HINDU ASTRONOMICAL AND MATHEMATICAL TEXTS SERIES No. 3

*General Editor*

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# BHĀSKARA I AND HIS WORKS

## PART II

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# MAHĀ-BHĀSKARĪYA

श्रीभास्कराचार्यविरचितम्

# महाभास्करीयम्

लखनऊ विश्वविद्यालयस्य गणिताध्यापकेन एम० ए०, डी० लिट्० इत्युपाधिधारिणा

श्री कृपाशंकर शुक्लेन

आङ्ग्लानुवाद-व्याख्या-टिप्पण्यादिभिः सहितं

सम्पादितम्

लखनऊ विश्वविद्यालयस्य गणित-ज्योतिष-विभागेन

प्रकाशितम्

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# PREFACE

The object of the "Hindu Astronomical and Mathematical Texts Series" is to bring out authoritative and critical editions of important unpublished works dealing with ancient Indian astronomy and mathematics. The present edition of Bhāskara I's *Mahā-Bhāskarīya* is No. 3 of this series.

The idea of bringing out the above series is due to Dr. A. N. Singh, late Professor of Mathematics, Lucknow University, who organised a scheme of research in the history of Hindu mathematics and astronomy in the Department of Mathematics, Lucknow University, with the object of collecting, studying, and editing important works on Hindu mathematics and astronomy. Under his able guidance remarkable progress was made in this direction and a number of manuscripts were acquired, studied and edited. In 1954 he submitted to the Government of the Uttar Pradesh a detailed plan for the publication of the work carried out under the above scheme of research in a series to be called the "Hindu Astronomical and Mathematical Texts Series". The plan was approved by the Government and a sum of Rs. 1000/- was sanctioned in the name of Bhārata Gaṇita Pariṣad to undertake the publication of the series. In the year 1955 the Government of the Uttar Pradesh was generous enough to sanction the remaining sum of Rs. 9000/- to the Department of Mathematics and Astronomy, Lucknow University, for the said publication.

The scheme of research in the history of Indian mathematics and astronomy referred to above has been financed by the Government of the Uttar Pradesh through the kind help of Dr. Sampurnanand, its then Education Minister, for which we express our sincere thanks to them. We are specially grateful to Dr. Sampurnanand who, a great scholar of Jyotiṣa as he himself is, has been taking keen interest in the progress of this research and helping us with necessary funds and encouragement from time to time.

R. Ballabh

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# TRANSLITERATION

## Vowels

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Short : | अ | इ | उ | ऋ | | | |
| | *a* | *i* | *u* | *ṛ* | | | |
| Long : | आ | ई | ऊ | ए | ऐ | ओ | औ |
| | *ā* | *ī* | *ū* | *e* | *ai* | *o* | *au* |

*Anusvāra* : ं = *ṁ*

*Visarga* : ः = *ḥ*

Non-aspirant : ऽ = '

## Consonants

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Classified : | क् | ख् | ग् | घ् | ङ् | | | |
| | *k* | *kh* | *g* | *gh* | *ṅ* | | | |
| | च् | छ् | ज् | झ् | ञ् | | | |
| | *c* | *ch* | *j* | *jh* | *ñ* | | | |
| | ट् | ठ् | ड् | ढ् | ण् | | | |
| | *ṭ* | *ṭh* | *ḍ* | *ḍh* | *ṇ* | | | |
| | त् | थ् | द् | ध् | न् | | | |
| | *t* | *th* | *d* | *dh* | *n* | | | |
| | प् | फ् | ब् | भ् | म् | | | |
| | *p* | *ph* | *b* | *bh* | *m* | | | |
| Unclassified : | य् | र् | ल् | व् | श् | ष् | स् | ह् |
| | *y* | *r* | *l* | *v* | *ś* | *ṣ* | *s* | *h* |
| Compound : | क्ष् | त्र् | ज्ञ् | | | | | |
| | *kṣ* | *tr* | *jñ* | | | | | |

# LIST OF ABBREVIATIONS

| | |
|---|---|
| *Ā* | *Āryabhaṭīya* |
| *BJ* | *Bṛhaj-jātaka* |
| *BrSpSi* | *Brāhma-sphuṭa-siddhānta* |
| *BṛSaṁ* | *Bṛhat-saṁhitā* |
| *GL* | *Graha-lāghava* |
| *KK* | *Khaṇḍa-khādyaka* |
| *KKau* | *Karaṇa-kaustubha* |
| *KKu* | *Karaṇa-kutūhala* |
| *KPr* | *Karaṇa-prakāśa* |
| *LBh* | *Laghu-Bhāskarīya* |
| *LMā* | *Laghu-mānasa* |
| *MBh* | *Mahā-Bhāskarīya* |
| *MSi* | *Mahā-siddhānta* |
| *MuCi* | *Muhūrta-cintāmaṇi* |
| *PiSi* | *Pitāmaha-siddhānta* (of *Viṣṇudharmottara-purāṇa*) |
| *PSi* | *Pañca-siddhāntikā* |
| *SK* | *Sarvānanda-karaṇa* |
| *ŚiDVṛ* | *Śiṣya-dhī-vṛddhida* |
| *SiSā* | *Siddhānta-sārvabhauma* |
| *SiŚe* | *Siddhānta-śekhara* |
| *SiŚi* | *Siddhānta-śiromaṇi* |
| *SiTV* | *Siddhānta-tatva-viveka* |
| *SūSi* | *Sūrya-siddhānta* |
| *TS* | *Tantra-saṅgraha* |
| *VSi* | *Vaṭeśvara-siddhānta* |
| *ViMā* | *Vidyā-Mādhavīya* |
| *VVSi* | *Vṛddha-Vasiṣṭha-siddhānta* |

# INTRODUCTION

This Part[1] contains the text with English translation, notes, short comments, and explanations, where necessary, of the *Mahā-Bhāskarīya* ("the bigger work of Bhāskara I").[2]

*Sanskrit Text.* The text has been edited on the basis of the following five manuscripts collected by the late Dr. A. N. Singh :

MSS. A and B —Containing the text only ;

MS. C —Containing the text together with a commentary entitled *Bhāṣya* of Govinda Svāmī ;

[1] The present work has been divided into four parts: Part I—General Introduction (containing a general study of the life and works of Bhāskara I); Part II—*Mahā-Bhāskarīya*; Part III—*Laghu-Bhāskarīya* ("The smaller work of Bhāskara I") edited with English translation, critical notes and comments, etc.; Part IV—Bhāskara I's commentary on the *Āryabhaṭīya* of *Āryabhaṭa* I.

[2] Bhāskara I, the author of the *Mahā-Bhāskarīya*, was a different person from his namesake of the twelfth century A. D., the author of the *Siddhānta-śiromaṇi* and *Līlāvatī*, etc. He lived in the seventh century of the Christian era and was a contemporary of Brahmagupta (628 A. D). He wrote three works on astronomy which were composed in the following order: (1) the *Mahā-Bhāskarīya*, (2) a commentary on the *Āryabhaṭīya*, and (3) the *Laghu-Bhāskarīya*. His commentary on the *Āryabhaṭīya* was written in 629 A. D., i. e., one year after the completion of the *Brāhma-sphuṭa-siddhānta* of Brahmagupta.

Bhāskara I was a follower of Āryabhaṭa I, the author of the *Āryabhaṭīya*. His works provide us with a detailed exposition of the astronomical methods taught by Āryabhaṭa I and throw light on the development of astronomy during the sixth and early seventh century A. D. in India. For details regarding the life and works of Bhāskara I, the reader is referred to Part I of the present work.

MS. D —Containing a commentary known as *Prayoga-racanā* and also supplying the beginnings of the passages commented upon ;

MS. E —Containing the commentary *Karma-dīpikā* of Parameśvara and also the beginnings of the passages commented upon.

MSS. A and B, which contain the text only, are in agreement in so far as the extent of the two is concerned. In other respects also they are almost the same. Both of them contain 396 verses. Agreement between the two manuscripts seems to indicate that they are perhaps derived from the same source. There are other reasons also for this conjecture. Verse iii. 45, which has been misplaced in one of them, occupies the same wrong position in the other also. Moreover, six and a half verses[1], which have been commented upon by Govinda Svāmī (MS. C), Parameśvara (MS. E), and in the *Prayoga-racanā* (MS. D), and are included in the text of MS. C, are absent from both MSS. A and B.

MS. C contains 394 and a half verses. Its text has evident gaps at some places, for a few verses, some of which have been actually commented upon in the commentary at their proper places, are missing from the text. These are amongst those verses which belong to MSS. A and B and have been explained in the *Prayoga-racanā* (MS. D), and in the commentary of Parameśvara (MS. E).

MSS. D and E contain commentaries of the *Mahā-Bhāskarīya*. In these manuscripts only the beginnings of the passages commented have been given ; the full text is not given.

The following table will show at a glance how far the above manuscripts have differed from one another :

[1] viz. i. 12 ; v. 18, 26-27(i), 47-48(i) ; vi, 14(ii)-15(i), 58(ii).

| Chapters and verses of the edited text | Whether available in MSS. A and B ? | MS C Whether available in the Text? | MS C Whether available in the comm.? | Whether commented upon in MS. D ? | Whether commented upon in MS. E ? |
|---|---|---|---|---|---|
| *Chapter I* | | | | | |
| Verses 1-7 | Yes | Yes | Yes | Yes | Yes |
| Verse 8 | Yes | No | ,, | ,, | ,, |
| Verses 9-11 | ,, | Yes | ,, | ,, | ,, |
| Verse 12 | No | ,, | ,, | ,, | ,, |
| Verses 13-52 | Yes | ,, | ,, | ,, | ,, |
| *Chapter II* | | | | | |
| Verses 1-10 | ,, | ,, | ,, | MS. defective | ,, |
| *Chapter III* | | | | | |
| Verses 1-74(i) | ,, | ,, | ,, | Yes | ,, |
| Verse 74(ii) | ,, | No | No | ,, | No |
| Verse 75(i) | ,, | No | Yes | ,, | Yes |
| *Chapter IV* | | | | | |
| Verse 1 | ,, | Yes | ,, | ,, | ,, |
| Verse 2(i) | ,, | No | ,, | ,, | ,, |
| Verses 2(ii)-12 | ,, | Yes | ,, | ,, | ,, |
| Verse 13 | ,, | No | ,, | ,, | No, but mentioned |
| Verses 14-64 | ,, | Yes | ,, | ,, | Yes |
| *Chapter* V | | | | | |
| Verses 1-17 | ,, | ,, | ,, | ,, | ,, |
| Verse 18 | No | ,, | ,, | ,, | ,, |
| Verses 19-25 | Yes | ,, | ,, | ,, | ,, |
| Verses 26-27(i) | No | ,, | ,, | ,, | ,, |
| Verses 27(ii)-46 | Yes | ,, | ,, | ,, | ,, |
| Verses 47-48(i) | No | ,, | ,, | ,, | ,, |

| Chapters and verses of the edited text | Whether available in MSS. A and B? | MS. C Whether available in the | | Whether commented upon in | |
|---|---|---|---|---|---|
| | | Text ? | Comm. ? | MS. D? | MS. E ? |
| Verses 48(ii)-78 | Yes | Yes | Yes | Yes | Yes |
| *Chapter VI* | | | | | |
| Verses 1-14(i) | ,, | ,, | ,, | ,, | ,, |
| Verses 14(ii)-15(i) | No | ,, | ,, | ,, | ,, |
| Verses 15(ii)-18 | Yes | ,, | ,, | ,, | ,, |
| Verse 19(i) | ,, | No | ,, | ,, | ,, |
| Verses 19(ii)-25 | ,, | Yes | ,, | ,, | ,, |
| Verse 26 | ,, | No | ,, | ,, | ,, |
| Verses 27-36(i) | ,, | Yes | ,, | ,, | ,, |
| Verse 36(ii) | ,, | No | ,, | ,, | ,, |
| Verses 37-40 | ,, | Yes | ,, | ,, | ,, |
| Verse 41 | ,, | No | ,, | ,, | ,, |
| Verses 42-58(i) | ,, | Yes | ,, | ,, | ,, |
| Verses 58(ii) | No | ,, | ,, | ,, | ,, |
| Verses 59-62 | Yes | ,, | ,, | ,, | ,, |
| *Chapter VII* | | | | | |
| Verses 1-35 | ,, | ,, | ,, | ,, | ,, |
| *Chapter VIII* | | | | | |
| Verses 1-22 | ,, | ,, | ,, | ,, | ,, |
| Verses 23-24 | ,, | No | No | ,, | ,, |
| Verses 25-27 | ,, | Yes | Yes | ,, | ,, |

The edited text of the *Mahā-Bhāskarīya* contains 402 and a half verses, of which 387 and a half occur in all manuscripts. The remaining fifteen verses, which occur either in MSS. A and B or in MS. C, are of the following categories :

(1) Those which have been commented upon by all commentators, viz. i. 8, 12; iii. 75(i); iv. 2(i); v. 18, 26-27(i), 47-48(i); vi. 14(ii)-15(i), 19(i), 26, 36(ii), 41, and 58(ii).

(2) Those which have been commented upon in one or two commentaries only, viz. iii. 74(ii); iv. 13; viii. 23-24.

Inclusion in the edited text of the verses of the first category requires no explanation. Those of the second category have been taken as genuine for the following reasons :

Half-verse iii. 74(ii). This has been regarded as genuine because it is relevant to the context and the subject matter contained in it has its counterpart in the author's smaller work, the *Laghu-Bhāskarīya*. It occurs in MSS. A and B and forms part of a passage [vv. 71-75(i)] which describes the occultation of certain stars by the Moon. This description is a statement of facts and hardly requires any explanation, which explains why the half-verse in question has been left unexplained by Govinda Svāmī and Parameśvara. The author of the commentary *Prayoga-racanā* has simply paraphrased it.

Verse iv. 13. The genuineness of this verse is evident from the mention of the word "*athavā*" (meaning "or") in the beginning of the next verse 14, which shows that verse 14 gives an alternative method. Verse 13 is thus indispensable, for if it is removed verse 14 would no longer be an alternative method. The author of the *Prayoga-racanā*, commenting on these two verses, states :

> "*viṣkambhārdha* etc. Here the author finds the true daily motion."[1]
>
> "*antyajīvā* etc. This is an alternative method."[2]

So also, commenting upon the verse 14, Parameśvara writes :

> "The author sets forth the method of finding the true daily motion by another method."[3]

Absence of the verse in question from the text of MS. C seems to be due to the carelessness of the scribe.

Verses viii. 23-24. These verses are taken as genuine because they occur in MSS. A and B and have been mentioned in MSS. D and E. Moreover, they have been mentioned and the examples contained therein have been solved in MS. C in Chapter I under verses 49 and 50 respectively. It seems that like so many other verses these also have been left out from MS. C due to the carelessness of the scribe. There is no doubt that they were composed by Bhāskara I, because they occur in his commentary on the *Āryabhaṭīya* along with several other verses containing similar examples.

There is one more verse which requires consideration here. It is not included in the numbered verses of the edited text. This verse marked 24* occurs after verse 24 of Chapter VIII. It does not occur in any of the available manuscripts of the *Mahā-Bhāskarīya*, but I have taken the liberty to include it in the edited text, though I have not given it any specific number. My reasons for including this verse in the text are as follows :

(1) The preceding verse 24 contains an example which

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1 विष्कम्भार्धेनेति स्फुटभुक्तिं साधयति ।

2 अन्त्यजीवेत्युपायान्तरम् ।

3 स्फुटभुक्त्यानयनं प्रकारान्तरेणाह ।

unlike other examples of that chapter, is of an abstract nature. In order to give that example a concrete form, it is necessary to supply some such data as mentioned in verse 24*.

(2) Verse 24 occurs in Bhāskara I's commentary on the *Āryabhaṭīya*[1] and in Govinda Śvāmī's commentary on the *Mahā-Bhāskarīya*[2]. At both the places it has been followed by verse 24* and the two verses taken together are treated as forming one complete example. The example has been solved both by Bhāskara I and Govinda-Śvāmī.

Counting this additional verse also, the edited text of the *Mahā-Bhāskarīya* consists of 403 and a half verses, which are distributed over the eight chapters as follows :

| Chapters | I | II | III | IV | V | VI | VII | VIII |
|---|---|---|---|---|---|---|---|---|
| Verses | 52 | 10 | $74\frac{1}{2}$ | 64 | 78 | 62 | 35 | 28 |

*Reading-differences.* The question of deciding between differing readings of the text as encountered in the manuscripts consulted by me has in general not presented much difficulty. In my choice between alternative readings I have been guided solely by the criterion of appropriateness. My task has been simplified by the fact that the readings selected and accepted should give the correct mathematical interpretation of the text as well as should fit in the metre.[3] Quotations from the *Mahā-Bhāskarīya* are found in other works. I have gathered together such quotations and this has helped me to verify the edited text in a number of cases.

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[1] ii. 32-33.

[2] i. 52.

[3] Metres used in the *Mahā-Bhāskarīya* have been arranged alphabetically at the end of the Sanskrit portion.

In some cases, however, alternative readings are possible and it may be that I have not given in the edited text the readings which might have occurred in the original. I have given in the foot-notes all alternative readings found in the various manuscripts consulted by me so that the interested reader may for himself decide whether the readings given in the edited text are appropriate or not.

*English Translation.* The question of translating technical material written in Sanskrit into English presents considerable difficulty. It requires a thorough knowledge of both languages which few can claim. My effort has been directed towards giving as far as possible a literal version in English of the text. The portions of the English translation enclosed within brackets do not occur in the text and have been given in the translation to make it understandable, and at places are explanatory. Without these portions the translation at places would appear meaningless to a reader who cannot consult the original for lack of knowledge of Sanskrit. I have tried my best to keep the spirit of the original and have as far as possible not altered the sequence in the translation. Sanskrit technical terms having no equivalents in English have been given as such in the translation. They are explained in the subjoined notes and the reader can always refer to the Glossary given in the end to find the meaning of such terms whenever the subjoined note does not contain the explanation of the terms.

Verses dealing with the same topic have been translated together and are preceded by an introductory heading briefly summarising their contents. In doing so I have followed the practice of the commentators.

The translation is followed by short notes and comments comprising (i) elucidation of the text where necessary, (ii) *rationale* of the rule given in the text, (iii) critical notes, and (iv) other relevant matter, depending on the nature of the passage translated.

*Technical Terms.* I have already pointed out (in Part I) the peculiarities of the language of the *Mahā-Bhāskarīya.* I have also noted that some of the technical terms used therein do not occur in other works. These technical terms are not found in Sanskrit lexicons, and I have succeeded in arriving at their correct interpretation and meaning by (i) the context, and (ii) comparison of the same or similar topics in other works available to me. The commentaries consulted by me have been of immense help, for without them quite a number of passages in the text would have remained obscure. In the foot-notes I have given references to parallel or similar passages found elsewhere, so that the reader may judge for himself whether I have arrived at correct interpretations or not.

At the end of this Part I have appended (1) a list of passages from the *Mahā-Bhāskarīya* quoted by later writers, and (2) a Glossary of terms used in the *Mahā-Bhāskarīya.*

In the end it is my sacred duty to express my great indebtedness to the late Dr. A. N. Singh for the help and guidance that I received from him in the preparation of the present edition of the *Mahā-Bhāskarīya.* I am also under great obligation to the late Dr. Bibhutibhusan Datta (*alias* Swami Vidyaranya) who kindly went through the whole of this work and gave valuable suggestions and advice.

My sincere thanks are due to Dr. Ram Ballabh, Professor of Mathematics, Lucknow University, for his suggestions and advice from time to time and for affording me all facilities in my researches. I am also thankful to Sri Gopal Dvivedi, Jyotisacharya, and Sri Markandeya Misra, Jyotisacharya, my Research Assistants, for the assistance rendered by them to me.

My thanks are also due to the Nav Jyoti Press, Lucknow, for their unfailing courtesy and care in the printing of this book.

K. S. Shukla

श्रीमद्भास्कराचार्यप्रणीतम्

# महाभास्करीयम्

—:०:—

## प्रथमोऽध्यायः

कलां बिभर्ति क्षणदाकरस्य यः
प्रकाशिताशां शिरसा गभस्तिभिः[1]।
नमोऽस्तु तस्मै सुरवन्दिताङ्घ्रये
समस्तविद्याप्रभवाय शम्भवे ॥ १ ॥

जयन्ति भानोः कमलावबोधिनः
करा हिमांशोर्वनितानन त्विषः[2]।
ससूरितारास्फुटदीर्घरश्मयो
धरासुतज्ञार्किसिततत्त्विषः[3] पुनः ॥ २ ॥

तपोभिराप्तं स्फुटतन्त्रमाश्मकं[4]
चिरत्वमभ्येतु[5] जगत्सु सद्गुणैः।
चिरं च जीव्यासुरपेतकल्मषा[6]
भटस्य शिष्या जितरागशत्रवः ॥ ३ ॥

नवाद्रिरूपाग्नियुतं[7] महीभुजां
शकेन्द्रनाम्नां गतवर्षसङ्ग्रहम्।
द्विषट्कनिघ्नं गतमाससंयुतं
युगाधिमासैर्गुणयेद् द्विराशितम्[8] ॥ ४ ॥

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[1] नमस्तिनि B. [2] हिमांशोर्वनिता···तत्विषः A, B. [3] धरासुतज्ञातिसितत्विषं A, B. [4] स्फुटतन्त्रमात्मकं C. [5] चिरं समभ्येतु A, B. [6] जीयासुरपेतकल्मषा A, B. [7] नवाग्निरूपाग्नियुतं A, B; नावाग्निरूपाग्नियुतं C. [8] युगार्धमासैगणयेद्विराशितम् B; युगाधिमासैर्गुणयेद्द्विराशिकम् C.

युगार्कमासाप्तगताधिमासकै-
यु॑तं[1] तिथिघ्नं[2] गतवासरैर्युतम्[3] ।
युगावमैस्तद् गुणयेद् द्विराशितं[4]
निशाकराहैर्विभजेत नित्यशः ॥ ५ ॥

तिथिप्रणाशाप्तिरतो विशोधिते[5]
भवत्यथाह्नां निचयः कलेर्गतः ।
वदन्ति[6] वारं [7]दितिसूनुपूजितात्
प्रवृत्तिमप्याहुरुदञ्चतो रवेः ॥ ६ ॥

शशाङ्कमासैरभिताडितान् हरे[8]-
दतीतमासानथवार्कसम्भवैः ।
[9]दिनीकृतान् भूमिदिनैर्हृतान् दिनै-
र्विभज्य लब्धशशिजैरहर्गणः ॥ ७ ॥

उदीरितान् यान् भगणान् क्षमादिनै-
र्लभामहे कान् कलियातवासरैः[10] ।
इति प्रलब्धा भगणास्ततः क्रमाद्
गृहांशलिप्ताविकलाः[11] सतत्पराः ॥ ८ ॥[12]

कलीकृतं वा ससमं[13] दिवाकरं
स्वगीतिकोक्तैर्भगणैः समाहतम्[14] ।
भजेत वर्षैर्युगसङ्ख्ययोदितै-[15]
र्विहङ्गमानां प्रवदन्ति लिप्तिकाः ॥ ९ ॥

निशाकरं वा ग्रहमुच्चमेव वा
कलीकृतं[16] तत्सहयातमण्डलैः ।

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[1] °युताः A; °युतः B. [2] The word तिथि here means 30, and not 15 as usual. [3] गतवासरान्वितम् A, B. [4] द्विराशितः A, B; द्विराशिकं C. [5] विशोध्यते A, B. [6] भवन्ति A, B. [7] तिथिसूनुपूजितात् A, B. [8] शशाब्दमासैरभिताडितान् C. [9] दिनीकृताद्भूमिदिनाहृतां A; दिनीकृताद्भूमिदिनाहतान् B, C. [10] उदीरितान्याद्भगणात्क्षमादिनैर्लभामहे तान् कलियातवासरैः A, B. [11] ग्रहांशलिप्ता° A, B, [12] Missing but commented upon in C. [13] [ससमं (= समाभिः सह वर्तमानं, ससमम्) means "together with years"] [14] समाहतः A; समाहतो B. [15] पक्षैर्युगसंख्ययोदितैः A, B. [16] कुलीकृतं C.

यथेष्टनक्षत्रगणैर्हृतं हरेत्
तदीयनक्षत्रगणैस्ततः कलाः ॥१०॥
युगाधिमासैर्द्युगणं हृतं हरेत्
क्षमादिनैर्वा भगणादि लभ्यते ।
त्रयोदशघ्ने सवितर्यथ[1] क्षिपे-
न्निशीथिनीनांपतिचारसिद्धये[2] ॥११॥
कुमुद्वतीनां सुहृदोऽथवाऽऽगतं
विशोध्य शेषस्य लवस्त्रयोदशः[3] ।
स मध्यमार्को गणकैर्निरूप्यते
गुरुप्रसादात्प्रतिबुद्धबुद्धिभिः ॥१२॥[4]
विना द्युराशेरपि[5] चन्द्रभास्करौ
प्रकुर्वतो वा विधिरेष कथ्यते ।
समासु मासीकृतविग्रहासु ये
ह्यतीतमासा विनियोज्य तान् पुनः[6] ॥१३॥
खरामनिघ्नान् दिवसेषु योजयेद्
गतेषु मासस्य ततोऽधिमासकैः ।
निहत्य सर्वं विभजेत सर्वदा
युगार्कमासैर्दिवसत्वमागतैः ॥१४॥
भवन्ति लब्धास्त्वधिमासकाः पुन-
स्ततोऽपनीयाशु च भागहारकम् ।
भजेत शेषं[7] शशिमाससङ्ख्यया
ततोंऽशलिप्ताविकलाः[8] सतत्पराः ॥१५॥
ततोऽधिमासान् प्रणिहत्य खाग्निभि-
र्नियोज्य[9] सम्यग्गतवासरैः क्रमात् ।
युगावमघ्नाञ्छशिवासरैर्हरेत्[10]
तमत्र शेषं प्रवदन्ति चाह्निकम् ॥१६॥

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[1] सवितर्यना A; सवितर्यता B. [2] निशीथिनीनां पथिचारसिद्धये A, C; निशीथिनानां पथिचारसिद्धये B. [3] च वस्त्रयोदश C. [4] Missing in A and B. [5] द्युराशेरबि A, B. [6] विनियोज्यतां पुनः C. [7] भवेदशेषाः A, B. [8] ततांशलिप्ताविकलाः A. [9] सुयोज्य A, B. [10] युगावमघ्नाच्छशिवासरैर्हरेत् A, B.

हत्वाऽधिमासैरवमस्य[1] शेषं
छित्त्वा धराया दिवसैः प्रलब्धम् ।
संयोज्य नित्यं त्वधिमासशेषे
कार्यं[2] पुनस्तत्करणैर्यथोक्तम् ॥१७॥
युगप्रसिद्धैर्धरणीदिनैर्हरे-
न्निहत्य षष्ट्यावमशेषमाह्निकम्[3] ।
कला विलिप्ताः क्रमशस्सतत्परा-
स्त्वतीतमासा दिवसा गृहांशकाः[4] ॥१८॥
त्रयोदशघ्नादपि रूपताडिता[5]-
द्विशोधयेद्यत्त्वधिमासशेषजम् ।
निशाकरार्कौ गणकैः प्रकीर्तितौ
भटप्रणीताविति बुद्धिमत्तमैः[6] ॥१९॥
अम्बरोरुपरिधिर्विभाजितो
भूदिनैर्दिवसयोजनानि तैः[7] ।
सङ्गुणय्य दिवसानथाहरेत्
कक्ष्यया भगणराशयः स्वया ॥२०॥
अदृष्टमन्यैरिदमाश्मकीयैः[8]
कर्म ग्रहाणां लघुतन्त्रसिद्धम् ।
सञ्चिन्त्य शास्त्रार्णवमाश्मकीय-
मुद्घाट्यते[9] तत्र[10] रहस्यभूतम् ॥२१॥
रुद्रैः सहस्रहतषट्छकलैश्च[11] हत्वा
वर्षाणि रन्ध्रवसुवह्निसमानसङ्ख्यैः ।
युक्त्वा[12] सदा प्रविगणय्य खरामभक्ते[13]
मासा भवन्ति दिवसाश्च हृतेऽवशिष्टाः[14] ॥२२॥
संहृत्य रन्ध्रयमलै[15] रसरामभागै[16]-
र्भूयोऽग्निवेदगुणितेषु हरेच्च भागम् ।

[1] हत्वाधिमासैरपरस्य A, B. [2] कार्यें A, B. [3] षष्ठ्यामवशेषमाह्निकम् B. [4] ग्रहांशकाः A, B, C. [5] रूप···डिता B. [6] बुद्धिमत्तरैः C. [7] भूदिनैर्दिवसयोजनोनितैः A, B; भूदिनैर्दिवसयोजनान्वितैः C. [8] अदृष्टमन्यैरिदमास्मकीयैः A, B; अदृष्टमान्यैरिदमाश्मकीयैः C. [9] उत्पाट्यते A, B. [10] तन्त्ररहस्यभूतम् A, B. [11] सहस्रहतषट्चकलैश्च B. [12] मुक्त्वा A, B. [13] खरामभक्तः A, B. [14] हृतेवऽशिष्टः B. [15] रन्ध्रयुगलैः C. [16] रसरामभक्तैः A, B.

खव्योमखद्विमुनिभिः[1] प्रलयस्तिथीनां
संयोज्य भूतयमरुद्रहृते दिनानि ॥२३॥
तेभ्योऽधिकाहान्प्रविशोध्य[2] शेषं
पातादतीतो[3] ह्यवमस्य कालः[4] ।
यदा न शुध्येदवमं[5] प्रगृह्य
दत्वा चतुष्षष्टिमतो[6] विशोध्यः ॥२४॥
मासाधिमासकगणाद्[7] गिरिभागशेषा-
त्त्रिंशद्गुणाद[8]पचयोऽयमुदीर्यतेऽतः ।
शैलावशिष्टकलियातमिषुप्रणिघ्नं
संयोज्य हीनदिवसेषु नगावशेषः[9] ॥२५॥
एकयुक्तदिवसेषु वर्षपः
[10]कीर्तितः सितखगादि तद्विदा ।
हीनरात्रगतयुक्तवासराद्
वेदवृन्दविहृतास्तदा[11]वमाः ॥२६॥
वर्षेषु रन्ध्रकृतचन्द्रसमाहृतेषु[12]
षट्सप्तपञ्चविहृतेषु दिनादिलाभः ।
ते योजिता दशहतासु [13]समासु संज्ञां
सम्प्राप्नुवन्ति रविजा इति निश्चयो[14] मे ॥२७॥
रविजदिवसयोज्याश्चावमा[15] येऽत्र[16] लब्धाः
सततमधिकमासाञ्छोधयेत्[17] खाग्निनिघ्नान् ।
भवति यदवशिष्टं शोधनीयं[18] समायां
यदि तदधिकशुद्धं क्षेप्यमेवोपदिष्टम् ॥२८॥

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[1] खव्योमवद्द्विमुनिभिः प्रलयस्थितीनां A; खव्योमवद्विमुनिभिः प्रलयस्थितीनां B. [2] तेभ्योऽधिकाहात्प्रविशोध्य A, B; तेभ्योऽधिकाहात्प्रणिशोध्य C. [3] वातारदातो A, B. [4] कालम् B. [5] शुध्येदपमं B. [6] दत्त्वा चतुष्षष्टितमो A, B. [7] मासाधिमासकगणा गिरिभागशेषाः A, B; मासाधिमासकगणान् गिरिभागशेषान् C. [8] द Missing from C. [9] नगावशेषम् A, B. [10] कीर्तितः स्थितखगादितीद्वदा A; कीर्तितस्थितखगादिती द्वदा B. [11] अपमाः B. [12] रन्ध्रकृतचन्द्रमसा हतेषु C. [13] समाससंज्ञां A, B; समाससंज्ञाः C. [14] निश्चलो A, B. [15] °चापमा B. [16] यत्र A, C. [17] सततमधिकमासाच्छोधयेत्…… निघ्नान् C. [18] शोधनीयां B.

षष्टिशतत्रयनिघ्नो वर्षगणो ग्रहतनुः सदा कथितः ।
तेन[1] समेता विहगा[2] ध्रुवका इति कीर्तिताः[3] सद्भिः ॥२९॥
मधुसितदिवसाद्यो हीनहीनो गणोऽह्नां
दिविचरहृतशिष्टो वारमाहाब्दपादिम्[4] ।
अत इदमपि शोध्यं शोधनीयं समायां
पतितसमतिरिक्तो गृह्यते नापरोऽत्र ॥३०॥
सप्तत्या दिवसाद्याश्शरभागा[5] द्विगुणिता विघटिकाश्च ।
तद्रहितो ग्रहदेहो रविबुधभृगवश्च निर्दिष्टाः ॥३१॥
कुमुदवनसुबन्धो रन्ध्रवर्गो द्वियुक्तो
ग्रहतनुगुणकारो भागहारः प्रदिष्टः ।
शरयमयमलाख्यो भागपूर्वोऽत्र लाभो
[6]हृचूणमपि शिवनिघ्ने खेन्द्रियाप्ता विलिप्ताः ॥३२॥
भागाः खत्रिघनांशास्त्रिरुद्रगुणिते[7] विलिप्तिका ज्ञेयाः ।
षड्भिः शतैर्विभक्ते विंशत्यंशो रवेश्च तमः ॥३३॥
अचलहतनवांशा लिप्तिका रुद्रनिघ्ने
[8]गगनरसविभक्ते लिप्तिकास्ता विपूर्वाः ।
ग्रहतनुखयमांशास्तत्पराः शोधनीया
दशलवसमवेत[9]श्चन्द्रतुङ्गः स भानोः ॥३४॥
भूभृद्रामहतां हरेच्छतगुणै[10] [11]रन्ध्रैर्ग्रहाणां तनुं
[12]भागाद्यास्फुजितो विमौरिकगणा[13] भागे शतेनोद्धृते ।
रामांशेन युतं रवेश्च सकलं द्विघ्नाद्रवेश्शोधये-
त्क्षेपः सोमजसोमयोः कृतगुणः सूर्योऽथ विश्वाहतः ॥३५॥
व्योमशून्यनेत्रभाजिते फलं
राशयोऽष्टभाजितेऽथ लिप्तिकाः[14] ।

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[1] तेन Missing from C. [2] बिभागा C. [3] ध्रुवका इति कीर्तितः B. [4] वारमासाब्दवादिः A, B. [5] सप्तद्या दिवसाद्याश्शरभाभागा C. [6] हृचुणमविशिखनिघ्नो वेन्द्रियाप्तावलिप्ताः A; हृचुणमविशिखनिष्ठो वेन्द्रियाप्ता विलिप्ताः B. [7] खत्रिदिनाशास्त्रिरुद्रगुणिते A; खत्रिघनांशास्त्रितरुद्रगुणिते C. [8] गगनरसविभक्तेर्लिप्तिकास्तापिपूर्वाः A, B. [9] °समुपेतः A, B. [10] हरेच्छरगुणै A, B. [11] °ग्रहाणान्तरं C. [12] भागाद्यास्थजितोऽपिमौरिकगणा A, B; भागाद्यास्फुजितोपि मौरिकगुणो C. [13] विमौरिकगणाः means विलिप्तागणाः । [14] लिप्तिकां विदुः A, B.

[1]बिन्दुषड्हृते विलिप्तिका विदुः
सर्वमेव योज्य गण्यते बुधः ॥३६॥
अष्टाहृते शरयमाश्विहृते कलाः स्यु-
र्देहे तथा त्रिशतभक्तविलिप्तिकाश्च[2]।
युक्त्वैतदेव[3]मुभयं शनिरत्र गण्य[4]-
स्त्रिशल्लवो रविभवो धनमत्र कार्यम् ॥३७॥
द्विकनिघ्ने ग्रहदेहे स्वविंशभागरहिते[5] तु लिप्ताद्याः।
पञ्चाशदंशविकलाः[6] क्षेप्या[7] भौमो रवेरर्धे[8] ॥३८॥
द्वियमघ्ने ग्रहदेहे शरनगरामोद्धृते[9] तु लिप्ताद्याः।
सुरनाथगुरोर्भोगो रविभोगद्वादशांशयुतः ॥३९॥
राशित्रयं क्षिप निशाकरतुङ्गमध्ये
[10]पातं निपात्य भगणात्[11] क्षिप राशिषट्कम्।
त्रैराशिकागतदिनेषु[12] च रूपमेकं
व्यावर्णयन्ति[13] गणका भटशास्त्रचित्ताः ॥४०॥
भूदिनेष्टगणा[14]न्योन्यभक्तशेषेण भाजितौ।
हारभाज्यौ दृढौ स्यातां कुट्टाकारं तयोर्विदुः ॥४१॥
भाज्यं न्यसेदुपरि हारमधश्च तस्य
खण्डयात्परस्परमधो विनिधाय लब्धम्[15]।
केनाऽऽहतोऽयमपनीय[16] यथाऽस्य शेषं[17]
भागं ददाति परिशुद्धमिति प्रचिन्त्यम्[18] ॥४२॥
[19]आप्तां मतिं तां विनिधाय वल्ल्यां
[20]नित्यं ह्यधोऽधः क्रमशश्च लब्धम्।

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[1] विन्दुषड्ढते विलिप्तिकां विदुः सर्वमेव योज्यते A; विन्दष·········ते विलिप्तिक द्विदस्सर्वमेव योज्यते B. [2] त्रिदशभक्तविलिप्तिकाश्च A, B; सदातिशतभक्तविलिप्तिकाश्च C. [3] मुक्त्वैतदेतदुभयं A; मुक्त्वैतदेवमुभयं C. [4] गण्याः A, B. [5] स्वविंशद्भागरहिते A, B. [6] पञ्चाशद्दशविकलाः A, B. [7] क्षेप्यो A. [8] रवेरर्थे C. [9] शरोगरामोद्धृते C. [10] वातं निपात्य B. [11] भगणान् C. [12] त्रैराशिकागतगुणेषु A. [13] प्रावर्तयन्ति C. [14] भूदिनेष्टगुणो A, B; क्ष्मादिनेष्टगणा C. [15] वल्यः A, B. [16] तेनाहृतोधंमपनीय A, B. [17] The reading स्वशेषं in place of °स्य शेषं has been mentioned by Govinda Svāmī in his commentary. [18] प्रचिन्त्य A, B. [19] अवेङ्च······तिम्नां A; अवंञ्च तिन्तां B. [20] नीतं A.

मत्या हतं स्यादुपरिस्थितं य-
ल्लब्धेन युक्तं परतश्च तद्वत् ॥४३॥
हारेण भाज्यो विधिनोपरिस्थो
भाज्येन नित्यं तदधःस्थितश्च ।
अह्नांगणो[1]ऽस्मिन् भगणादयश्च
तद्वा[2] भवेद्यस्य समीहितं यत्[3] ॥४४॥
रूपमेकमपास्यापि कुट्टाकारः प्रसाध्यते ।
गुणकारोऽथ लब्धं च राशी स्यातामुपर्यधः ॥४५॥
इष्टेन शेषमभिहत्य भजेद् दृढाभ्यां[4]
शेषं दिनानि[5] भगणादि च[6] कीर्त्यतेऽत्र ।
राश्यादयो निरपवर्तितवासरघ्ना[7]
राश्यादिमानभजिताः[8] प्रवदन्ति शेषम् ॥४६॥
भाज्योऽधिको[9] यदि भवेत् खलु हारराशे-
स्तत्राधिकं समपनीय तथैव कर्म ।
तेनाधिकेन गुणितो गुणकारराशि-
र्युक्तोऽधरेण स भवेत् पृथगत्र लब्धम् ॥४७॥
अपवर्तितवासरादिशेषात्
क्रमशस्तानपनीय रूपपूर्वम् ।
कृतकुट्टनलब्धराशिमेषां[10]
गुणकारं समुशन्ति वारहेतोः ॥४८॥
छेदभाज्यापवर्तेन[11] यच्छेदस्यातिरिच्यते ।
तेन हारं समभ्यस्य वेलाकुट्टस्तु पूर्ववत् ॥४९॥
प्रक्षिप्य भागहारं कुट्टाकारे पुनः पुनः[12] प्राज्ञैः ।
योज्यं च भागलब्धं भाज्ये[13] प्रस्तारयुक्त्यैव[14] ॥५०॥
गन्तव्यमिष्टं यदि कस्यचित्स्याद्-
गन्तव्ययोगादिदमेव कर्म ।

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[1] अहर्गणो A, B, C. [2] तष्ट्वा A; त......B. [3] च A, B. [4] भुजेद्दृढाभ्यां C. [5] दिनादि A, B. [6] म B. [7] निरपवर्जितवासरघ्ना A, B. [8] राश्यादिमानभजितां A, B. [9] भाज्याधिको A, B. [10] कृत्तकुट्टनलब्धराशिशेषां B. [11] छदे भाज्यापवर्तेन A; छेद-भाज्यापवर्तना C. [12] पुनः Missing from A, B. [13] भाज्ये Missing from C. [14] प्रस्तारयुक्ते वा A, B.

रूपेण वा योज्य विधिर्विचिन्त्यः[1]
सर्वं समानं खलु लक्षणेन ॥५१॥
योगेषु तेषां भगणादियोगै-
र्विशेषितैर्वापि तथा विशेषे[2]।
अन्योन्यशेषादपि चिन्तनीय-
मिष्टग्रहस्पष्टगणैर्विधानम् ॥५२॥

इति महाभास्करीये प्रथमोऽध्यायः ।

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[1] योन्यविधिर्विचिन्त्य A, B. [2] विशेषैः C.

# द्वितीयोऽध्यायः

लङ्कातः खरनगरं सितोरुगेहं
पाणाटो[1] मिसितपुरी तथा तपर्णी[2]।
उत्तुङ्गस्सितवरनामधेयशैलो
लक्ष्मीवत्पुरमपि[3] वात्स्यगुल्मसंज्ञम्[4] ॥ १ ॥[5]

विख्याता वननगरी[6] तथा ह्यवन्ती[7]
स्थानेशो मुदितजनस्तथा च मेरुः।
अध्वाख्यः[8] करणविधिस्तु मध्यमाना-
मेतेषु प्रतिवसतां न विद्यते सः ॥ २ ॥

अक्षांशान्निगदितपत्तनांशहीनान्[9]
संहन्यान्नवनवपक्षपुष्कराख्यैः।
अष्टाभिश्शरकृतिभागहीनसङ्ख्यै-
श्चक्रांशैरपहृतयोजनानि[10] कोटिः ॥ ३ ॥

कर्णाख्यः स्वगदितपत्तनान्तराध्वा[11]
तिर्यक्स्थो जनपदभाषितो[12] जगत्याम्।
तत्कृत्योर्विवरपदं वदन्ति केचि-
दध्वानं ग्रहगणितस्य वेदितारः[13] ॥ ४ ॥

अध्वानं गणितविदो भटस्य शिष्याः[14]
स्थूलत्वाच्छ्रवणविधेर्न सम्यगाहुः।
अक्षादेरपि च विधेरथोपपत्तिं[15]
वक्रत्वात् क्षितिपरिधेर्वदन्ति[16] सन्तः ॥ ५ ॥

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[1] वाणाटो A, B. [2] तथातपण्णि A, B. [3] लक्ष्मीवत्परमपि A. [4] खात्यगुल्म° A, B. [5] From पाणाटो to वात्स्यगुल्मसंज्ञम् is missing from C. [6] परनगरी C. [7] तथा ह्यवन्ति B; तथाप्यवन्ती C. [8] निन्ध्याख्यः A; विन्ध्याख्यः B; अधाख्यः C. [9] स्वाक्षांशाणिगदितवित्तनाशहीनात् A, B. [10] चन्द्रांशैः° A, B. [11] स्वविहितपत्तनान्तरध्वा A; स्वविहितपत्तनान्तरद्धा B; स्वगदितपत्तनान्तराध्वा C. [12] जनवदभाषितो B. [13] गणितस्य वेदितारम् A; गणितस्य वेदिस्तारम् B. [14] शिष्यान् C. [15] विधेरथोपपत्ति B; विधेरथाप्रवृत्ति C. [16] चक्रत्वात्क्षितिपरिधेर्भवन्ति C.

छायाप्तस्फुटदिवसार्धतिग्मरश्म्यो[१]-
रध्वानं विवरकलाग्रमाहुरेके ।
नैतत् स्यात् समपरपूर्वदिक्स्थितानां
तुल्यत्वात् पलगणितस्य[२] वर्णयन्ति ॥ ६ ॥

सूर्येन्द्वोरकृतसमाध्वनोर्विधानात्
सम्प्राप्तस्थितिदलदृष्टकालयोश्च[३] ।
विश्लेषः स्फुटतर उच्यतेऽत्र कालो
गोलज्ञैर्विदितभटप्रणीततन्त्रैः[४] ॥ ७ ॥

नित्यं वा शशिनमदेशकालसङ्ख्यं
सूर्यञ्च[५] स्फुटमुदयास्तगं[६] घटीभिः ।
कृत्वैवं जलविधिना घटीश्च बुद्ध्वा
[७]तन्त्रज्ञा विवरमुशन्ति देशकालम् ॥ ८ ॥

ग्रहोदयो यदा पूर्वं[८] स्पर्शः पश्चाच्च लक्ष्यते[९] ।
पूर्वेण समरेखाया द्रष्टा[१०] स्यात्पश्चिमेऽन्यथा ॥ ९ ॥

कालेनाहत्य भुक्तिं ग्रहरवितमसां देशजातेन नित्यं
षष्ट्या हृत्वाऽथ लब्धं जलपसुरपयोर्दिग्गतानां धनर्णे[११] ।
लम्बेनाहत्य भूमेः सकलगुणहृते वृत्तसङ्ख्यां घटीभि-
र्हृत्वा[१२] देशान्तराभिर्गगनरसहृते योजनाग्रं वदन्ति[१३] ॥१०॥

इति महाभास्करीये द्वितीयोऽध्यायः ।

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[१] छायार्धस्फुटदिवसस्थतिग्मरश्म्योः A; छायार्थस्फुटदिवसतिग्मरश्म्योः B; छायार्धतिग्मरश्म्योः C. [२] फलगणितस्य A, B. [३] सम्प्राप्तस्सतिदलकालदृष्टयोश्च A, B. [४] गोलोक्तैर्विदितभटप्रणीतनेत्रः A, B. [५] सूर्यश्च A, B. [६] स्फुटमुदयास्तथा A; स्फुटमुदयास्तथङ् B; स्फुटमुदयास्तनं C. [७] तत्र स्याद्विवरमुशन्ति A; तत्रस्य द्विपरमुशन्ति B. [८] पूर्वः C. [९] स्पर्शश्चैवोपलक्ष्यते A, B; स्पर्शश्चैवोपलभ्यते C. [१०] भ्रष्टा A, B. [११] षष्ट्या हृत्वाथ लब्धा जलवसुरवयोर्दिग्गतानां धनर्णे A; षष्ठ्या हृत्वाथ लब्धा जलवसुरवयो र्दिग्गतानां धनर्णे B; षष्ट्या हृत्वाथ लब्धः जलवसुरवयो दिग्गतानां धनं तत् C. [१२] हृत्वा C. [१३] In MSS A and B the last two lines read as follows: लम्बेनाभ्यस्य भूमेस्सकलगुणहृतो वृत्तसंख्याघटीभिर्हृत्वा देशान्तराभिर्गगनरसहृतो योजनाग्रं वदन्ति ।

# तृतीयोऽध्यायः

अद्भिः समत्वमवगम्य[1] धरातलस्य
वृत्तं लिखेत् स्फुटतरं खलु कर्कटेन ।
सूत्रैश्चतुर्भिरवलम्बकसन्निबद्धै[2]-
[3]र्ज्ञातार्जवोरुसमवृत्तगुरुर्नरः स्यात् ॥ १ ॥

छायाप्रवेशनिर्गमबिन्दुभ्यां[5] मीनमालिखेद् व्यक्तम्[6] ।
[7]तद्वक्त्रपुच्छनिःसृतं सूत्रं याम्योत्तरं शङ्कोः ॥ २ ॥

बिन्दुभिस्त्रिभिरतुल्यकालजैः
संलिखेच्छफरिके विधानतः ।
सूत्रयोर्मुखसमप्रयातयो[8]-
र्योगतः कुजबुधाशयोर्विधिः ॥ ३ ॥

नृच्छायाकृतियोगस्य मूलमाहुर्मनीषिणः[9] ।
विष्कम्भार्धं[10] स्ववृत्तस्य छायाकर्मणि सर्वदा ॥ ४ ॥

छायाहतं त्रिभवनस्य[11] गुणप्रतानं[12]
हृत्वा नरेण च पृथग्विभजेत्पदेन ।
अक्षावलम्बकगुणौ[13] विषुवत्प्रसिद्धौ
छायानरौ च विपुलावपरत्र दृष्टौ ॥ ५ ॥

इष्टज्यां मुनिरन्ध्रपुष्करशशिक्षुण्णां सदा संहरेद्
व्यासार्धेन भवेदपक्रमगुणस्तात्कालिकस्तत्कृतिम् ।
विष्कम्भार्धकृतेर्विशोध्य[14] च पदं द्युव्यासखण्डं[15] विदुः
स्वेष्टक्रान्तिहतं पलं[16] प्रविभजेल्लम्बेन जीवा क्षितेः[17] ॥ ६ ॥

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[1] समत्वमधिगम्य A, B. [2] अवलम्वततं निबद्धैः A; अवलम्वत तन्निवद्धैः B. [3] जाता° C. [4] समवृत्त is missing from A, B. [5] छायाप्रवेशनिर्गमवीन्दुभ्यां C. [6] वृत्तम् C. [7] तद्वत्क्रपुच्छनिःसृतं सूत्रं याम्मोत्तरं A; तद्वक्तृपुच्छनिःसृतसूत्रं याम्मोत्तरं B.; तद्वक्त्रपुच्छनिर्गतसूत्रं याम्मोत्तरे C. [8] °प्रयान्तयोः B. [9] मुखमाहुर्मनीषिणः C. [10] विष्कम्भार्धा A, B. [11] त्रिभुवनस्य A, B, C. [12] गुणव्रतानं C. [13] अक्षावलङ्क-गुणने C. [14] व्यासार्धस्य कृतेर्विशोध्य C. [15] पदाद् द्युव्यासखण्डं A; पदा······न्यासखण्डं B; पदं दव्यासखण्डं C. [16] फलं A, B; परं C. [17] क्षितौ C.

व्यासखण्डगुणितं[1] क्षितेर्गुणं
संहरेद् दिवसजीवया[2] पुनः ।
काष्ठितं[3] च यदवाप्तमत्र तु
प्रोच्यते चरदलं[4] सतां वरैः ॥ ७ ॥

जिना दशघ्ना यमरन्ध्रशालिनो[5]
निशाकराष्टौ गुणिताः पलाङ्गुलैः[6] ।
हृताश्चतुर्भिः क्रिय-गो-नरान्तजा
भवन्ति निःश्वासलवाः चरोद्भवाः[7] ॥ ८ ॥[8]

शशिकृतशशिरामैराहता राशिजीवाः
स्वकदिवसगुणार्धैर्भाजिताः[9] काष्ठिताश्च[10] ।
पतितसमतिरिक्ताः पूर्वचापैरजाद्यै-[11]
र्विषुवदुदयराशिप्राणपिण्डाः क्रियाद्याः[12] ॥ ९ ॥

खनगरसशशाङ्काः पञ्चरन्ध्राद्रिरूपा[13]
विषयशिखिनवैकास्ते च दृष्टा विधिज्ञैः ।
चरदलपरिहीणा योजिता व्युत्क्रमेण
प्रतिविषयसमुत्थास्तूदया मेषपूर्वाः[14] ॥१०॥

अपगमपलभागा[15] मेषजूकादिगोले
रहितसहितसङ्ख्या मध्यसूर्यावनामः[16] ।
अवनतिलवहीनः प्रोन्नतिश्चक्रपाद-
स्त्ववनतिलवजीवा सा प्रभा नेतरा[17] स्यात् ॥११॥

क्षितिजाद्युदलसमासो विश्लेषो वोत्तरेतरे गोले ।
लम्बघ्नस्त्रिज्याप्तः शङ्कुर्दिनमध्यगे[18] सूर्ये ॥१२॥

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[1] .व्यासखण्डगुणिता A, B. [2] संहरेद् द्युदलजी° A; संहरेद्युदलजी° B. [3] काष्ठिकं A, B [4] परदलं C. [5] कृतरन्ध्रभूमयो A, B; यम......शालिनो C. [6] नवादयस्ते गुणिता वलाङ्गुकैः A; नवादियस्तेगुणिता वलाङ्गुलै B. [7] वलोद्भवाः A, B; पलोद्भवाः C.
[8] Parameśvara quotes the following reading of this verse in his *Siddhānta-dīpikā*:

वसुत्रिदस्रा गुणरन्ध्रभूमयो नवाद्रयश्चाभिहताः पलाङ्गुलैः ।
हृताश्चतुर्मिः क्रियगोयमान्तजाश्चरासवः स्युः क्रमशस्तु चापिताः ॥

[9] स्वधिदि° A, B. [10] काष्ठिकाश्च B. [11] पूर्वचापैरजाद्या A; पूर्वचापैरजाद्या B. [12] भवन्ति A, B. [13] खनगरसशशाङ्कां पञ्चरन्ध्राश्विरूपा A; खनगरसशशाङ्कां पञ्चरन्ध्राश्मिरूपा B. [14] तूभयोर्वेषपूर्वाः C. [15] अपगमवलभागा A, B. [16] मध्यसूर्यावनामम् A, B. [17] नेतरा=ना+इतरा । [18] शङ्कुर्दीनमध्यगे B.

छायया समभिनीतसन्नतेः[१]
काष्ठतोऽधिकतरं यदा पलम्[२] ।
तद्भिदः[३] स्फुटरवेरपक्रम—
स्तिग्मरश्मिरपि चोत्तरे तदा ॥१३॥

छायायां याम्यकाष्ठायामक्षयुक्ता[४] नतिः स्फुटा ।[५]
जायन्तेऽपक्रमा भागा[६] भास्वतोऽदक्षिणापथे[७] ॥१४॥

अक्षतोऽधिकतरा यदा नतिः
पात्यते पलमतस्तदा सदा[८] ।
शिष्यतेऽपमधनुः[९] स्फुटं ततो
भास्करोऽपि खलु याम्यगोलगः ॥१५॥

तद्गुणेन गुणितां त्रिराशिजां
ज्यामपक्रमगुणेन[१०] संहरेत् ।
लब्धचापगणिते पदक्रमाद्[११]—
भास्करस्त्रिकसषण्णवाधिकः ॥१६॥

उत्तरे संयुतिः[१२] सूर्ये विश्लेषो दक्षिणे स्मृतः ।
अपक्रमनतांशानां[१३] छायायां[१४] च पलं भवेत् ॥१७॥

दक्षिणोत्तरगते विवस्वति
प्राणराशिनिचयाद् धनक्षयौ[१५] ।
स्वाक्षजं[१६] चरदलं सदा ततो[१७]
जीवयाऽत्र गुणितं दिवागुणम् ॥१८॥

संहरेत् त्रिभवनस्य[१८] जीवया
तत्र लब्धनिचये क्षितेर्गुणम् ।

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[१] समभिनीतसंगतेः A, B; समभिनीतसन्ततेः C. [२] लवम् A, B. [३] तद्भिद B; तत्क्षय C. [४] °क्षयोज्या C. [५] This hemistich is missing from B. [६] भोगो A; भागो B. [७] अपक्रमधनुर्भागा जायन्ते दक्षिणापथे C. [८] पश्यते वलमतस्तदा सता A, B. [९] °तेवमधनुः A; °तेवमतनु C. [१०] व्योमवक्रमगुणेन C. [११] लब्धचापगुणिते स्फुटं ततः A, B. [१२] योजयेत् C. [१३] अपिक्रमनतांशानां A, B; अवक्रमनतांशोनां C. [१४] जायायां C. [१५] प्राणराशिनिचया धनक्षयौ A, B; प्राणराशिविचयाद्धगक्षयौ C. [१६] साक्षजं A, B. [१७] सतो A, B. [१८] त्रिभुवनस्य A, B, C.

व्यत्ययं चरदलस्य तत्कुरु
स्वावलम्बकहृतं हरेत् पुनः ॥१९॥
व्यासखण्डनिचयेन लभ्यते
शङ्कुरिष्टघटिकासमुद्भवः[1] ।
व्यासतत्कृतिविशेषजं[2] पदं
कथ्यते स्फुटतरा प्रभा सदा[3] ॥२०॥
आदित्यलग्नविवरांशगुणेन हत्वा
तत्कालमध्यपरिनिष्ठितलम्बकाख्यम् ।
विष्कम्भभेदभजितः[4] स्फुटशङ्कुरुक्त[5]–
स्तद्गोलभेदकृतिशुद्धपदं प्रभा स्यात्[6] ॥२१॥
रविकक्ष्यामध्यज्यात्रिज्याकृत्योर्विशेषशेषपदम्[7] ।
तत्कालमध्यजातो गोलज्ञैर्लम्बकः कथितः ॥२२॥
प्राणैश्चरैर्युतविहीनघटीगुणेन[8]
तज्ज्याविपर्ययकृतेन[9] हृतस्य वाऽस्य ।
द्युव्यासलम्बकपरस्परताडितस्य
छेदोऽर्धविस्तरकृतिः फलमस्य शङ्कुः ॥२३॥
तज्ज्याविपर्ययकृतं[10] द्युज्याभ्यस्तेन शङ्कुना हृत्वा ।
विषुवत्कर्णाभ्यस्ता त्रिज्या छेदः[11] फलं शङ्कुः ॥२४॥
इष्टासुभ्यश्चराशुद्धौ[12] व्यत्ययः शेषजीवया ।
प्राग्वल्लब्धं क्षितेर्मौर्व्या[13] हित्वा शङ्कुः[14] स्वकर्मणा ॥२५॥
शर्वर्यां शङ्कुरर्कस्य कार्यो व्यस्तेन कर्मणा ।
दिनस्य[15] क्षयवृद्धिभ्यां रात्रौ व्यस्तेन ते यतः ॥२६॥
इष्टच्छायाप्तशङ्कुं सकलगुणहतं[16] संहरेल्लम्बकेन
प्राप्ते मेषादिगेऽर्के[17] क्षितिजगुणकलाः शोधयेद्दक्षिणस्थे ।

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[1] °समुद्भवा A, B. [2] °विशेषजा A, B; °विशेषकं C. [3] हि सा A, B. [4] विष्कम्भभेदरहिता A, B. [5] स्फुटशङ्कुरुक्तं A. [6] वा B. [7] इनरविकक्ष्यामध्यज्यात्रिज्याकृत्योर्विशेष्यशेषपदम् A, B; रविकक्ष्यामध्यज्याकृत्योर्विशेषशेषपदम् C. [8] प्राणैश्चरैर्यत° C. [9] तज्याविपर्ययगुणेन B. [10] तज्ज्याविपर्ययकृता A, B. [11] च्छेदः A, B, C. [12] इष्टासभ्यश्चराशुद्धेन A, B; इष्टादिभ्यश्चराशुद्धौ C. [13] क्षितेर्मौर्व्या C. [14] शङ्कुं A; शंकु B. [15] अह्नस्तु C. [16] सकलगुणहतां A, B. [17] मेषा··गोले C.

योज्यन्ते ताः क्रमेण त्रिगृहगुणहतं[1] संहरेच्छेषराशिं
द्युव्यासार्धेन चापे[2] स्वचरदललवव्यत्ययेनासुराशिः ॥२७॥
अह्नः शेषो गतो वा रस–खरसहृतो[3] नाडिकाद्याः प्रदिष्टाः
त्रिज्यावर्गाहतं[4] वा स्वमभिमतनरं[5] भाजयेद् घातजेन[6] ।
द्युव्यासार्धाक्षकोट्योः[7] स्वचरदलगुणे पूर्ववत्कल्पितस्य
चापे प्राणाश्चराख्याः[8] पुनरपि विधिना व्यत्ययेनासुराशिः ॥२८॥

अक्षकर्णहृतः[9] शङ्कुर्भूयो व्यासार्धताडितः ।
शङ्कुघ्नद्युदलाप्तो[10] वा पूर्ववन्नाडिकाविधिः ॥२९॥
सूर्यागतसमभ्यस्ताः तद्राशीष्टासवो[11] हृताः ।
राशिभागैः कलाभिर्वा लब्धा रव्यगतासवः[12] ॥३०॥
इष्टासुभ्यो विशोध्यैतान् रवौ चाप्यगतं[13] क्षिपेत् ।
राशिप्राणांस्ततोऽपास्य देया भानौ च राशयः ॥३१॥
शेषं[14] त्रिंशत्समभ्यस्तमिष्टराश्यसुभिर्हृतम् ।
लब्धभागादिसंयुक्तमिष्टकालोदयं विदुः[15] ॥३२॥
पूर्वलग्नं[16] सचक्रार्धमस्तलग्नं विधीयते ।
उदयस्यवशादस्तमयन्ते राशयो यतः[17] ॥३३॥
उदयस्य गता [18]भागाः स्वोदयेन हता हृताः ।
त्रिंशता प्राणलब्धिः स्यात् लग्नराश्यसवः पुनः ॥३४॥
आहार्या[19] यावदर्कस्य राशिभिस्तूदयासवः ।
जायन्ते पुनरर्कस्य गन्तव्यांशासुभिर्युताः ॥३५॥
प्राणा दिवसशर्वर्योर्विज्ञेयाः[20] षड्विभाजिताः ।
षष्ट्या[21] भूयोऽपि ये लब्धा घटीविघटिकासवः ॥३६॥

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[1] त्रिगुणगुणहता C. [2] द्यावासेनाप्तचापे A, B; द्युव्यासार्धाप्तचापे C. [3] रसखरसहृते C. [4] स्त्रिष्ट्यौ वर्गाहतं C. [5] समभिमतनरा A, B. [6] सातजेन C. [7] द्युव्यासार्धाक्षकोट्या A, C; द्युव्यासार्धाभकोट्या B. [8] प्राणैश्चराख्यैः A, B. [9] अक्षकर्णनतः: C. [10] अङ्कघ्नद्युदलाप्ताद् C. [11] समभ्यस्ता तद्रासिष्टासवो A; समभ्यस्ता तद्राशिष्टासवो B; समभ्यस्तात्तद्राशिष्टासवो C. [12] रव्यहतासवः C. [13] विशोध्यैता रवौ चान्यगतः A, B; विशोध्यैनां स्रवौ चाप्यगतं C. [14] शेषः C. [15] विधिः C. [16] पूर्वलग्ना A, B. [17] गताः C. [18] भागा सोदयेन A, B. [19] आहार्यं A, B. [20] दिवसशर्वर्योविज्ञेयाः A, C; दिसशर्वर्योविज्ञेया B. [21] षष्ठ्या B.

स्फुटरविभुजनिघ्नां यां[1] परां क्रान्तिजीवां
हरतु समवलम्बज्याकलापेन भूयः ।
स्फुटदिवसकराग्रा सा यदाऽक्षांशहीना
रविरपि यदि गोले चोत्तरे लम्बकघ्नाम्[2] ॥३७॥

अक्षज्यया हरेद् भूयः शङ्कुः स्यात् सममण्डले[3] ।
तद्वर्गव्यासकृत्योर्यद् विश्लेषं तत्पदं[4] प्रभा ॥३८॥

भानोर्भुजामभिहतां परमापमेन[5]
द्युव्यासभेदभजिताप्तहताक्षकोटिः ।
अक्षज्ययाप्तकृतिशुद्धकृतेस्त्रिमौर्व्या[6]
मूलस्य काष्ठमसवो गगनावधेर्वा ॥३९॥

व्यासार्धताडितवपुः सममण्डलस्य
दृग्ज्याऽथवा[7] दिवसविस्तरभेदभक्ता ।
लब्धस्य कार्मुकविधेरसुनाडिकास्ता[8]
भास्वत्खमध्यविवरप्रभवा भवन्ति ॥४०॥

छायाभिनीतसमण्डलशङ्कुनिघ्न-
मक्षस्य [9]यद्गुणमुपाहर नित्यमेव ।
सर्वापमेन[10] समवाप्तधनुर्विवस्वान्[11]
युक्त्या[12] त्रिराशिसहितश्च भटप्रणीतः[13] ॥४१॥

अर्काग्राशङ्क्वग्रे छायां च यथेष्टकालिकां कृत्वा ।
अग्रद्वयस्य योगस्तुल्याशस्यान्यथा विवरम्[14] ॥४२॥

तेन क्षुण्णां छायां भङ्क्त्वा तद्दृग्गुणेन[15] यल्लब्धम् ।
कृतदिग्विभागकेन्द्राद् दिग्विपरीतं निधातव्यम् ॥४३॥

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[1] स्फुटरविभुजनिघ्ना यां A; स्फुटरविभुजनिघ्नायां B. [2] लम्बकघ्नाः A, B. [3] शङ्कुज्यासममण्डले A, B. [4] तद्वर्गव्यासकृत्योर्यद्विश्लेषे यत्पदं A, B; तद्वर्गव्यासकृयोस्तविश्लेषेऽल्पपदं C. [5] भानोर्भुजामविहतां परमावमेन A; भानोर्भुजामविहितां परमावमेन B; भानोर्भुजामतिहतां परमावमेन C. [6] °या प्रकृति° B. [7] दृश्याथवा A,B; दृग्ज्याः··· C. [8] काष्ठकविधेरसुनाडिकास्ताः A, B. [9] यद् missing from A, B. [10] सर्वावमेन A, C. [11] समवाप्ततनुर्विवस्वान् A, B. [12] युज्या A, B. [13] भटप्रणीतम् A, B. [14] योगतुल्यांशं नान्यथा विवरः A, B; गोलस्तुल्याशस्यान्यथा विवरम् C. [15] तद्द्युगुणेन A; तद्युगुणेन B.

तन्मत्स्यभेदिसूत्रं[1] प्रागपरदिशोः प्रसार्यते दूरम् ।
छायाप्रमाणसूत्रं तिर्यक्केन्द्रादिदं नेयम्[2] ॥४४॥
बिन्दुद्वयं[3] विरच्यं पूर्वापरयोर्दिशोर्यथायोगम् ।
मध्यच्छायाशिरसि ज्ञेयो बिन्दुस्तृतीयोऽन्यः[4] ॥४५॥[5]
यो वा स्यादविदितदिग्विभागकेन्द्रो[6]
दिक्छायाभ्रमणविधिं[7] प्रकर्तुकामः ।
तस्याशास्फुटलिखितोरुवृत्तनेमिं[8]
न[9] च्छाया त्यजति यथा तथा प्रवक्ष्ये[10] ॥४६॥
इष्टद्युतेस्तु[11] कृत्वा दृग्ज्यां[12] शङ्कुं तथा च[13] शङ्क्वग्रम् ।
विश्लेषो वाऽग्रयुतिर्बाहुः[14] कर्णोऽत्र दृग्जीवा[15] ॥४७॥
तत्कृतिविश्लेषपदं[16] दृग्ज्याकर्णस्य[17] कथ्यते कोटिः ।
छायाघ्ने कोटिभुजे दृग्ज्याभक्ते[18] तयोर्माने ॥४८॥
शङ्कोस्त्वक्समवपुषस्त्वृजवो[19] भुजकोटिमानसङ्घटिताः[20] ।
वंशशलाकास्ताभिः कोणे कृतशङ्कुसञ्चारम् ॥४९॥
चतुरश्रं द्युतिकर्णं त्रिभुजं[21] वा कारयेत् स्फुटं यन्त्रम्[22] ।
विन्यस्यैतद् भ्रमयेच्छायाकर्णानुगा यावत् ॥५०॥
आशा भुजकोटिभ्यां[23] छायाकर्णाग्रयोरुभौ बिन्दू ।
मध्यच्छायाशिरसि ज्ञेयो बिन्दुस्तृतीयोऽन्यः[24] ॥५१॥
बिन्दुत्रयस्य[25] सकलस्य शिरोवगाहि
संलिख्यते शफरिकाद्वितयेन[26] वृत्तम् ।

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[1] तन्मध्यभेदिसूत्रं A, B; तन्मध्ये भेदसूत्रं C. [2] ज्ञेयम् A, B. [3] ...हबिन्दुद्वयं A, B; बिन्दुत्रयं C. [4] बिन्दुस्तुतियायत् A; विन्दस्तुतियायत् B. [5] In MSS A and B, verse 45 occurs after verse 47. [6] स्यादभिहिततद्विभागकेन्द्रो A; स्याद-भितदिग्विभागकेन्द्रो B. [7] धिं missing from B. [8] °वृत्तनेमिः A, B; तस्याशाः स्फुटलिखितोऽत्रवृत्त° C. [9] य A, B. [10] च वक्ष्ये C. [11] इष्टद्विकेस्तु A; इष्टद्विकैस्तु B. [12] दृज्यां A, B. [13] च missing from B. [14] विश्लेषो वाग्रयुतिं प्राहुः A, B. [15] दृज्जीवा A, B. [16] तत्कृतिविशेषपदं C. [17] दृज्याकर्णस्य A, B. [18] दृज्ज्या-भक्ते A; दृज्याभक्ते B. [19] शङ्कोस्तत्समवपुषस्त्रिजवो A, B; शङ्कुस्त्वर्कसमवपुषस्त्वृ-जवो C. [20] मान missing from A, B. [21] चतुरश्रं द्वितीयकर्णं त्रिभुजं A; चतुर-श्रन्द्वितीयकर्णं त्रिभुजं B; चतुरश्रद्युतिकर्णं त्रिभुजं C. [22] यत्र C. [23] आशाभुजकोटिज्यां A, B. [24] बिन्दुसूतियोऽन्यः A, B. [25] बिन्दुद्वयस्य C. [26] सफरिकौ द्वितयेन A, B; शफरिकान्वितयेन C.

तन्मण्डलाग्रविनिवेशितमस्तकेयं
छाया[1] प्रयाति फणिनीव हि[2] मन्त्ररुद्धा ॥५२॥
इष्टक्रान्तिक्षितिजावर्गसमासस्य मूलमर्काग्रा[3] ।
क्षितिजा व्यासार्धहता सूर्याग्रहृता[4] पलस्य[5] गुणः ॥५३॥
अक्षजीवाहतः[6] शङ्कुरिष्टकालसमुद्भवः ।
भाजितो लम्बकेनाथ शङ्क्वग्रं नित्यदक्षिणम् ॥५४॥
शङ्क्वग्रे द्वादशाभ्यस्ते स्वेष्टशङ्कुहृते फलम् ।
छाया वैषुवती[7] ज्ञेया विस्तरश्चापि कथ्यते ॥५५॥
ग्रीवासमां[8] भगणभागविभक्तवृत्तां
कुर्यात् स्थलीं समतलां कृतदिग्विभागाम्[9] ।
तस्या जलेशदिशि मण्डलमध्यदृष्टि-
र्विध्याद्रविं[10] परिधिलग्नमनाकुलात्मा ॥५६॥
पूर्वरेखाग्रवेधस्य रविवेधस्य चान्तरम् ।
अर्काग्राचापनिर्माणं परिधौ[11] भागलक्षिते ॥५७॥
अर्काग्रा ज्या भवेत्तस्य तन्नतिज्याविशेषजा[12] ।
लिप्ता[13] शङ्क्वग्रजीवाया दक्षिणे चोत्तरेऽन्यथा ॥५८॥
दक्षिणाभिमुखी छाया यदा भवति भास्वतः ।
नतिज्यारहिताकार्ग्रा शङ्क्वग्रं कथ्यते तदा ॥५९॥
विद्धि तेन[14] विषुवत्प्रभां सतीं[15]
पूर्ववच्च पललम्बकौ[16] पुनः ।
वेदितव्यविदितग्रहान्तरं
नाडिकाभिरवगम्य तत्त्वतः[17] ॥६०॥
षड्गुणास्तु[18] घटिका लवास्तु तैः[19]
पूर्वपश्चिमदिशि स्थिते क्षयः[20] ।

[1] मस्तके यच्छाया A, B; मस्तके यज्जाया C. [2] फणिनि वह्नि C. [3] °समासपद-मुच्यतेऽर्काग्रा C. [4] सूर्याग्रं हृता B. [5] वलस्य A, B. [6] इष्टजीवाहतः A; इष्टनीवा-हतः B. [7] वष्ठपति B. [8] दिवोसमां A, B; ग्रीवां समां C. [9] स्थलीनमत प्राकृत-दिग्विभागाम् A, B; स्थलीं समतुलां कृतदिग्विभागाम् C. [10] विद्याद्रविं A, B, C. [11] परितो A, B. [12] °विशेषजाम् C. [13] लिप्त्वा C. [14] केन C. [15] सती A, B. [16] पूर्ववच्च चललम्बकौ A, B; पूर्ववच्चावलम्बकौ C. [17] तत्परः A, B. [18] तद्गुणास्तु A, B. [19] कैः A, B. [20] ऽक्षधीः C.

उच्यते धनमपि[१] क्रमेण त-
ज्ज्ञातचारनिचयैः सदा[२] बुधैः ॥६१॥
एवं नक्षत्रताराणां ग्रहैस्ताराभिरेव च ।
साधितं क्षेत्रनिर्माणं युक्त्या सर्वत्र सर्वदा ॥६२॥
अष्टौ भानि क्रिये, षट् स्युरेकोना[३] विंशतिर्वृषे ।
द्वौ दिशो मिथुने, द्वौ च तिथयस्त्र्यष्टकं[४] परे ॥६३॥
अष्टौ सार्धास्त्रिसप्तैने[५], वेदाः शैलोनकन्यकाः[६] ।
पञ्चाद्र्येकं तुलाराशौ, द्वाविनोऽष्टादशाः[७] परे ॥६४॥
एकोऽब्धीन्दुस्त्रिरन्ध्राणि[८] चापे, भूतैकषड्यमाः[९] ।
मृगेऽद्रिर्द्व्यूनकुम्भे[१०] तु पञ्चेन्द्वन्त्येऽश्विभादितः[११] ॥६५॥
योगभागाः[१२] क्रमेणैते बोद्धव्यास्तेऽश्विभादिषु[१३] ।
उदगाशार्कभूतानि दक्षिणे पञ्चदिग्भवाः[१४] ॥६६॥
उदग्रसास्तथाकाशं दक्षिणे पर्वतोऽम्बरम्[१५] ।
उदगर्कश्च ते[१६] सैका दक्षिणे सप्त चाश्विनौ ॥६७॥
सप्तत्रिंशदुदग्भागा[१७] याम्ये सार्धांशकास्त्रयः ।
अब्धयोऽष्ट त्रिभागाश्च[१८] स्वरास्ते सत्रिभागकाः ॥६८॥
उदक् त्रिंशत् कृतिः षण्णां याम्ये लिप्तास्त्रिषट्ककाः ।
उदग्जिना द्विविश्वे[१९] च विहायः कीर्त्यतेऽपरम्[२०] ॥६९॥
विक्षेपांशाः क्रमेणोक्ता बोद्धव्यास्तेऽश्विभादिषु[२१] ।
योगभागसमाः सर्वे दृश्यन्ते योगजा ग्रहाः ॥७०॥

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[१] धनमता A, B; ऽयनमपि C. [२] क्रमेण⋯ज्ञातचा⋯निचयैः समा C. [३] स्युः एकोऽजा A, B. [४] तिथयस्त्वष्टकं A, B, C. [५] सार्धा त्रिसप्तैने A, B; सार्धास्त्रिसप्तैनै C. [६] शैलोनिताः परे A, B. [७] द्वौ विनाष्टादशा A; द्वौ विनाष्टादशाः B. [८] एकोऽपीन्दुस्त्रिरन्ध्राणि A, C. [९] चापभूतैकषष्ठ्युमा A, B. [१०] मृगेद्रिर्भूनिताः कुम्भे A, B; मृगेऽद्रिद्यूनकुम्भ C. [११] पञ्चेन्द्विन्तेऽश्वि° A; पंचेन्द्वन्तेऽश्वि° B; °ऽश्विनादयः C. [१२] योगभागः B; यागभागाः C. [१३] बोद्धव्याश्शशिभादिषु A; वोद्धव्याश्चाश्विनादिषु B. [१४] दक्षिणे वाद्यनायनम् A; दक्षिणे वाद्यानयनं च दिग्भवाः B. [१५] उदग्रसास्तथाकाश दक्षिणे पर्वताम्बरम् A; उदग्रसास्तथाकाश दक्षिणे पर्वतांवरम् B; उदग्रास्तास्तथाकाशा दक्षिणे पर्वताम्बरम् C. [१६] उदगर्थाश्च ते A; उदगर्थाश्चेत B; उदगार्कश्वते C. [१७] सप्तत्रिंशदुदग्भावा A, B. [१८] अद्रचब्दयोऽद्रिभागाश्च A; अद्रचब्धयोद्रिभागाश्च B. [१९] उदिग्जिनाश्विलिप्ते A, B; उदग्जीना द्विविश्वे C. [२०] कीत्यते वरा A, B. [२१] °श्विनादिषु C.

विक्षेपांशैस्तयोः साध्यमन्तरं ग्रहतारयोः ।
उच्यते[1] क्षिप्तिलिप्ताभिर्हन्तीन्दुर्दक्षिणागतः ॥७१॥
रोहिणीशकटं षष्ट्या[2] त्वष्टिवर्गेण[3] तारकाम्[4] ।
नवत्या सार्धया चित्रां[5] द्विशत्या शक्रतारकाम्[6] ॥७२॥
शतेन चार्धयुक्तेन[7] मैत्रं शतभिषग्जिनैः[8] ।
नवत्या द्व्यूनयैन्द्राग्नं[9] पौष्णं विक्षिप्तिवर्जितम्[10] ॥७३॥
उत्तरेण शते षष्टौ[11] बहुलाभेद[12] उच्यते ।
उत्तरां परमां गत्वा मघामध्यस्थतारकाम्[13] ॥७४॥
यष्टियुक्तकलास्त्वेता ग्रहैर्नक्षत्रभेदने ॥७५(i)॥[14]

इति महाभास्करीये तृतीयोऽध्यायः ।

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[1] उच्यन्ते C. [2] भषष्ट्याः A, भषष्ठ्याः B. [3] त्वष्टवर्गेण C. [4] तारकाः A, B. [5] पित्रां C. [6] विंशत्या शक्रतारकाम् A, B; द्विशत्या शात्रतारकाम् C. [7] स्वार्धयुक्तेन A, B. [8] शतभिषा जिनैः A, B; शतभिषग्जनैः C. [9] द्व्यूनयैन्द्राग्रं A, B; द्यूनयैन्द्राग्रं C. [10] विक्षिप्तवर्जितः A, B; विक्षिप्तवर्जितम् C. [11] शतेनाष्टौ A, B. [12] बहुलं भेद A, B. [13] त्यक्त्वा मध्यं विश्वस्य तारका A; मत्वा मध्यं विश्वस्य तारका B. [14] उत्तरां·····भेदने missing from C.

## चतुर्थोऽध्यायः

कृत्वा देशान्तरं कर्म रवेरुच्चं विशोधयेत् ।
शेषं[1] सूर्यस्य यत्केन्द्रं[2] तस्मिन् राशित्रयं पदम् ॥१॥
जीवाः क्रमोत्क्रमाभ्यां तु ग्राह्याः केन्द्रपदक्रमात् ।[3]
जीवानां[4] ग्रहणोपायः[5] कथ्यते विस्तरेण सः ॥२॥
लिप्तीकृत्य हरेन्मख्या जीवा लब्धास्ततः पुनः ।
वर्तमानाहृतं शेषं मख्या चैव विभाजयेत् ॥३॥
पूर्वसङ्कलिते युक्ते ज्याः क्रमेणोत्क्रमेण[6] वा ।
स्वपरिध्याहतेऽशीत्या लब्धं क्षयधनं[7] फलम् ॥४॥
केन्द्रात्पदविभागेन क्षयधनधनक्षयाः[8] ।
देशान्तरकृते[9] सूर्ये कुर्यात्तन्मध्यमे सदा ॥५॥
केन्द्रे क्रियादिके[10] चाथ फलं बाहोर्विशोधयेत् ।
तुलादिके तु तन्नित्यं देयं स्फुटदिदृक्षुणा[11] ॥६॥
क्रमोत्क्रमफलाभ्यस्ता मध्या[12] बाहुफलेन[13] वा ।
भुक्तिश्चक्रकलालब्धं[14] पूर्ववत्तत्प्रकल्पयेत् ॥७॥
बाहुकोटी[15] क्रमात्केन्द्रे कोटिबाहू[16] गतागते ।
तयोर्गुणफले प्राग्वत् कर्णार्थे[17] परिकीर्तिते[18] ॥८॥
आद्ये पदे चतुर्थे च व्यासार्धे कोटिसाधनम् ।
क्षिप्यते शोध्यते चैव शेषयोः कोटिका भवेत् ॥९॥
तद्बाहुवर्गयोगस्य मूलं[19] कर्णः प्रकीर्तितः ।
बाहुकोटिफलाभ्यस्ते कर्णे व्यासार्धभाजिते ॥१०॥

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[1] शिष्टः C. [2] तत्केन्द्रं C. [3] जीवाः ····पदक्रमात् missing from C. [4] जीवाया A, B. [5] ग्रहणोपायं C. [6] ज्याक्रमेणोत्क्रमेण C. [7] स्वपरिध्याहताशीत्या भक्तोऽक्षयधनं C. [8] क्षयं घनघनक्षयाः A; क्षय्यं धनधनक्षयाः B. [9] देशान्तरीकृते A C. [10] केन्द्रात्-क्रियादिके A, B. [11] केन्द्रक्रियादिगे वा फलं वाहोर्विशोध्यते । तुलादिगे च तन्नित्यं देयं स्फुटदिदृक्षुभिः ॥ C. [12] क्रमोत्क्रमफलाभ्यस्तां मध्यां A, B. [13] वाहुःफलेन A. [14] भुक्ति-श्चक्रकलावाप्ता A, B. [15] बाहुकोटि A, B, C. [16] कोटिबाहु B, C. [17] प्राग्वत्कर्णार्धो C. [18] परिकीर्त्यंते A, B. [19] तद्बाहुवर्गसंयोगमूलं A, B.

भुजाकोटिफले स्यातां ताभ्यां[1] कर्णश्च पूर्ववत् ।
भूयः पूर्वफलाभ्यस्ते कर्णे त्रिज्याविभाजिते ॥११॥
एवं पुनः पुनः कुर्यात्कर्णः[2] पूर्वोक्तकर्मणा ।
यावत्तुल्यो भवेत्कर्णः पूर्वोक्तविधिनाऽमुना[3] ॥१२॥
विष्कम्भार्धहता भुक्तिः सूर्याचन्द्रमसोः सदा ।
स्वाविशेषेण कर्णेन स्फुटभुक्तिरवाप्यते ॥१३॥[4]
अन्त्यजीवाऽथवा भुक्त्या गुणिता धनुषा हृता ।
स्वपरिध्याहतेऽशीत्या लब्धे हीनाधिके स्फुटा[5] ॥१४॥
अन्त्यजीवाधनुःखण्डं केन्द्रभोगाद्विशोधयेत्[6] ।
तद्विशोध्य मखेश्शेषं[7] पात्यतेऽविषमे[8] ततः ॥१५॥
उच्चभुक्तिविहीनाया भुक्तेः[9] शीतांशुमालिनः ।
उत्क्रमज्या क्रमे ग्राह्या क्रमज्या चोत्क्रमस्थिते[10] ॥१६॥
आद्यन्तयोः फलं युक्त्वा[11] गुणयोश्चानुपाततः ।
तत्फलेन[12] विहीनाढ्या भुक्तिः स्फुटतरा हि सा ॥१७॥
ह्यस्तनाद्यतनयोर्यो विश्लेषोऽतीतभोगकः[13] ।
श्वस्तनाद्यतनयोश्च भावी भोगः[14] प्रकीर्तितः ॥१८॥
कोट्यां पदवशाद्धित्वा युक्त्वा वाऽन्त्यफलं पुनः ।
तद्वर्गबाहुवर्गस्य योगात्कर्णः पदं[15] भवेत् ॥१९॥
कर्णेनान्त्यफलं हत्वा विष्कम्भार्धेन लभ्यते ।
पूर्वकोट्यां धनर्णं[16] स्याद्यावत् कर्णः[17] समो भवेत् ॥२०॥
भुजज्याभिहता त्रिज्या[18] कर्णेनाप्तधनुः क्रमात् ।
केन्द्रात्पदविभागेन धनं स्वोच्चे प्रकल्पयेत् ॥२१॥

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[1] स्यातामाभ्यां C. [2] °कर्ण A, B. [3] यावत्तुल्या भवेत्संख्या कर्णस्य विधिनामुना C. [4] Missing from C. [5] स्वपरिध्याहताशीत्या लब्धा हीनाधिका स्फुटा C. [6] केन्द्रभागाद्वशोधयेत् A, B. [7] तद्विशुद्धमधः शेषं A, B; तद्विशोध्यमखेश्शेषः C. [8] पात्यते विषमे A, B, C. [9] भक्ते A, B. [10] चेत्क्रमे° A, B. [11] युक्त्या C. [12] तत्फलेह° C; °विहीनाप्ता A, B. [13] ह्यस्तनाद्यतनयोर्विशेषोऽतीतभोगतः A; ह्यस्तनाद्यतनयोपिशेषोऽतीतभोगतः B. [14] भाविभोगः A, B. [15] तद्वर्गबाहुवर्गस्य यः कर्णः······पदं C. [16] पूर्वकोट्या धनर्णं A, B; पूर्वकोट्यायनर्णं C. [17] स्याद्यावान्कर्णः A, B. [18] भुजाज्याभिहता त्रिज्या B; भुजज्याहतां त्रिज्यां C.

तदेव केवलं पूर्वं चक्रार्धं तेन वर्जितम् ।
चक्रार्धं तच्च चक्राच्च संशुद्धं[१] स स्फुटो रविः ॥२२॥
प्रतिमण्डलसंसिद्धिरेषा सम्यक् प्रकीर्तिता ।
स्वान्त्यं[२] फलं च सर्वेषामुच्यते प्रतिमण्डलम् ॥२३॥
स्फुटस्वदेशमध्यार्कविश्लेषान्तरसंगुणा ।
भुक्तिश्चक्रकलावाप्तं[३] पूर्ववत्तद्[४] भुजान्तरम् ॥२४॥
त्रयोदशहता[५] जीवा त्रिस्फुटस्य विवस्वतः ।
द्वात्रिंशता हृता क्रान्तिः परिशेषस्तु पूर्ववत् ॥२५॥
चरप्राणहता[६] भुक्तिरहोरात्रासुभाजिता[७] ।
उदयास्तमयोः[८] शुद्धिः क्षेपश्चोत्तरगे रवौ ॥२६॥
व्यत्ययो दक्षिणे भानावन्येषामनुपाततः[९] ।
फलं च तद्वशाद्विद्धि[१०] क्षेपः शोधनमेव वा ॥२७॥
उदक्चरार्धसंयुक्तः पादोऽहोरात्रसम्भवः[११] ।
दिनार्धं दक्षिणे हीनं[१२] राज्यर्धं तद्विपर्ययात् ॥२८॥
सूर्यबाहुहता भुक्तिर्मध्या चक्रकलाहृता[१३] ।
भास्करस्य वशात् क्षेपः शुद्धिर्वापि निशाकृतः ॥२९॥
शेषं विवस्वता तुल्यं कर्म चन्द्रस्य कीर्तितम् ।
भास्वद्भुजाफलेनैव शेषाणां तु प्रकल्पयेत् ॥३०॥
स्फुटार्कोनः[१४] शशी छेद्यो लिप्ताभिः खद्विभूधरैः[१५] ।
तिथयस्तत्र लभ्यन्ते शेषं षष्ट्या[१६] समाहतम् ॥३१॥
छिन्द्याद् भुक्तिविशेषेण घटीविघटिकासवः ।
तिथेश्शेषो[१७] गतो वापि निर्दिष्टो भास्करोदयात् ॥३२॥

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[१] संशुद्धं चक्रोच्चः A; संयुक्तं चक्रोच्चः B; चक्राच्च संशुद्धः C. [२] स्थान्त्यं C. [३] चक्रकलाप्राप्ता A, B. [४] पूर्ववत्ते C. [५] त्रयो शुहता B. [६] चरप्राणाहता C. [७] भुक्तिरहोमात्रासुभाजिता B; भुक्तिरहोरात्रन्तभाजिता C. [८] उदयास्तगयोः A, B; उदयास्तमययोः C. [९] भानावन्येषामनुपात्ततः A, B; भानामन्येषामनुपाततः C. [१०] फलं भास्वद्वशाद्विद्धि A; फलं च तद्वशात्सिद्धि C. [११] उदक्परार्धसंयुक्तः पादाहो° A; उदक्परार्धसंयुक्तः वादोहो° B. [१२] हीने C. [१३] भुक्तिर्मध्यचन्द्रकला° A, B; °चक्रकलामता C. [१४] स्फुटार्थोनः A, B. [१५] ...खभूधरैः C. [१६] षष्टचा समं न्यसेत् A; षष्ठचा समभ्यसेत् B. [१७] तिथिः शेषो A, B.

तिथ्यर्धहारलब्धानि करणानि बवादितः[1] ।
विरूपाणि सिते पक्षे सरूपाण्यसिते विदुः ॥३३॥
लिप्तीकृतो ग्रहश्छेद्यः शतैरष्टाभिराप्यते[2] ।
ज्योतिषां निचयो यातो भुक्त्या शेषाद् घटीर्विदुः[3] ॥३४॥
सूर्येन्दुयोगे चक्रार्धे व्यतीपातोऽथ वैधृतः[4] ।
चक्रे च मैत्रपर्यन्ते[5] विज्ञेयः सार्पमस्तकः[6] ॥३५॥
नानायने व्यतीपातस्तुल्यापक्रमयोस्तयोः ।
उद्देशस्तस्य चक्रार्धं[7] विक्षेपात्त्वधिकोनकम्[8] ॥३६॥
तिग्मांशुकेन्द्रवज्जीवाः[9] क्रमशश्चोत्क्रमादपि ।
भुजाकोट्यादिसिद्धिश्च विशेषोऽतोऽभिधास्यते ॥३७॥
स्ववृत्तान्तरगुणां ज्यां[10] पदयोरोजयुग्मयोः ।
क्रमोत्क्रमात् त्रिमौर्व्याप्तां[11] परिधौ परिकल्पयेत् ॥३८॥
क्षयोऽधिकाद्युतिर्हीने[12] परिधिः स्यात् स्फुटो मतः[13] ।
तेनाहतेष्टकेन्द्रज्यां[14] छित्वाऽशीत्या[15] फलं विदुः ॥३९॥
स्वमन्दकेन्द्रसंप्राप्तफलचापार्धमिष्यते[16] ।
पदक्रमाद्यथा भानोः स्वमध्ये तद्विधीयते ॥४०॥
शीघ्रकेन्द्रफलाभ्यस्तं विष्कम्भार्धं विभज्यते[17] ।
स्वकर्णेनाप्तचापार्धं[18] कार्यं तस्मिन्विपर्ययात्[19] ॥४१॥
तस्मान्मन्दफलं[20] कृत्स्नं कार्यमिष्टं स्वमध्यमे ।
एवं भौमार्किजीवानां[21] विज्ञेयाः स्फुटमध्यमाः ॥४२॥

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[1] बहूदितः C. [2] शरैरष्टाभिराप्यते A, B; शकैरष्टाभिराप्यते C. [3] शेषाद्घटीं विदुः A; शेषात् घटिं विदुः B; शेषघटीर्विदुः C. [4] वैधृतम् C. [5] चक्रे मैत्रे च पर्यन्ते A, B. [6] सार्वमस्तकः A, B, C. [7] नानात्मने व्यतीपाते सूर्योपक्रमयोस्तयोरुद्देशस्तत्सम्पातार्धं C. [8] विक्षेपादधिकोन्नतम् A; विक्षेपादधिकोनतम् B. [9] तिग्मांशुः केन्द्रवज्जीवा A, B; तिग्मांशुकेन्द्रवज्जीवां C. [10] स्ववृत्ता स्वोत्तरगुणा A, B; स्ववृत्तान्तरगुणाज्यां C. [11] क्रमात्क्रमात्त्रिमौर्व्याप्तां A; क्रमात्क्रमात्त्रिमौर्वाप्तं B. [12] क्षयेऽधिकद्युती हीने A; क्षयोऽधिकद्युती हीने B; क्षयोऽधिकाद्युतिहीने C. [13] स्यात्स्फुटा मता A, B. [14] तेनाहतैर्ग्रहेन्द्रज्यां A, B. [15] जित्वाशीत्या C. [16] मन्दकेन्द्रस्थसंप्राप्तं फलं चा° A; मन्दकेन्द्रस्य प्राप्तफल° B. [17] विभाजयेत् A, B. [18] स्वकर्णेनाप्तस्य चा° C. [19] कार्यन्तिविपर्ययात् C. [20] तस्मिन्मन्दफलं A, B. [21] भौमार्कजीवानां A. B.

तद्विहीनचलोत्पन्नफलचापेन[१] संस्कृतः ।
स्फुटमध्यः स्फुटो[२] ज्ञेयः शेषयोरुच्यते विधिः ॥४३॥
शीघ्रन्यायाप्तचापार्धयुक्तहीनो[३] विपर्ययात् ।
मन्दोच्चः स्फुटमध्यस्य[४] कर्ता शीघ्रात् स्फुटं विदुः[५] ॥४४॥
प्रतिमण्डलकर्मापि योज्यमत्र विपश्चिता ।
मन्दोच्चे पूर्ववत्कुर्याच्छीघ्रोच्चात्तद्विशोध्यते[६] ॥४५॥
तदेव केवलं शोध्यं चक्रार्धाच्छोध्य तच्चलात् ।[७]
चक्रार्धसंयुतञ्चापं चक्राच्छुद्धं च शेषयेत् ॥४६॥[८]
स्फुटवृत्तगुणां त्रिज्यां हृत्वाऽशीत्या स्वकोटितः[९] ।
त्यक्त्वा पदेषु युक्त्वा वा कर्णः प्राग्वत् प्रसाध्यते[१०] ॥४७॥
मन्दोच्चसिद्धतन्मध्यविश्लेषार्धसमन्वितः[११] ।
मन्दसिद्धेऽधिके हीने रहितो मध्यमो ग्रहः ॥४८॥
स शीघ्रोच्चात्पुनः साध्यः सिद्धयोरन्तरालजम्[१२] ।
अर्धीकृत्य सकृत्सिद्धे पूर्ववत् परिकल्पयेत् ॥४९॥
एवं कृतस्य भूयोऽपि मन्दसिद्धिं समाचरेत् ।
मन्दसिद्धस्य तस्यायं विशेषोऽतोऽभिधास्यते[१३] ॥५०॥
द्विसिद्धमन्दसिद्धस्य[१४] द्विसिद्धस्य यदन्तरम् ।
प्राग्वत्तन्मध्यमे कृत्वा शीघ्रसिद्धः[१५] स्फुटो ग्रहः ॥५१॥
एवमारार्किजीवानामाख्यातं[१६] प्रतिमण्डलम् ।
शेषयोरप्ययं सम्यगुच्यते यो विधिक्रमः[१७] ॥५२॥
शीघ्रोच्चसिद्धतन्मध्यविश्लेषार्धसमन्वितम् ।
मध्यान्न्यूनेऽधिके हीनं मन्दोच्चं संस्कृतं[१८] विदुः ॥५३॥[१९]

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[१] तद्विहीनफलोत्पन्नफलंचापेन A, B. [२] स्फुटमध्यस्फुटो A, B, C. [३] शीघ्रस्यावाप्तचापार्धं युक्तहीनो A, B. [४] मन्दोच्चस्फुटमध्यस्य A, B, C. [५] शीघ्रस्फुटं पुनः C. [६] °शीघ्रोच्चं तद्विशोधयेत् A, B. [७] तदेव केवलं योज्यं पादयोः पूर्ववच्चलात् A; तदेव केवलं योज्यं पदयोः पूर्ववच्चलात् B; तदेव केवलं शोध्यं पदयोः पूर्वयोश्चलात् C. [८] चक्रार्धसंयुतश्चापं चक्राच्छोध्यश्च शेषयोः A; चक्रार्धसंयुतश्चापं चक्राच्छोध्यश्च शेषयोः B. [९] भङ्क्त्वाशीत्या स्वकोटिता C. [१०] कृत्वा पदेषु युक्ता वा कर्णं यावत् प्रसाध्यते C. [११] °समन्वितम् C. [१२] सिद्धयोरन्तरा भुजम् A, B. [१३] विश्लेषोऽतो विधास्यते A, B. [१४] ततो द्विसिद्धमन्दस्य A, B. [१५] शीघ्रसिद्ध C. [१६] एवमारार्कजी° C. [१७] विधिः क्रमः B. [१८] संस्कृते A. [१९] मध्यादूनेऽधिके हीनं मन्दमेवं तु कर्मणा B.

बुधभृग्वोः पुनस्साध्यं मान्दमेवं स्वकर्मणा[1] ।[2]
तेन सिद्धौ चलाद् भूयः स्फुटावेतौ[3] प्रकीर्तितौ ॥५४॥
कोटेरन्त्यफलं शोध्यं न शुध्येद् व्यत्ययस्तदा ।
कार्यः[4] कर्णोऽसकृन्मान्दः सकृत्कर्णस्तु शीघ्रजः[5] ॥५५॥
स्फुटमध्यमान्तरदलं मध्यवशादृणं धनं[6] चले कृत्वा ।
वक्रातिवक्रगमने[7] विज्ञेये तन्निवृत्तिश्च ॥५६॥
शीघ्रोच्चात् स्फुटखेचरो निपतितः शेषो[8] यदा राशय-
श्चत्वारो यदि वक्रगत्यभिमुखः षट् चातिवक्रे[9] स्थितः ।
अष्टौ चेत्कुटिलं जहाति विहगः पन्थानमाश्वेव स[10]
त्वैष्यातीतविचारिणोर्विवरकं[11] भुक्तिर्भवेदाह्निकी[12] ॥५७॥
मन्दान्त्यजीवागुणितां[13] स्वभुक्तिं
भूयः स्ववृत्तेन हृतां विभज्य ।
राशेः कलाभिर्दशताडिताभि-
र्भुक्तौ धनर्णं पदयुक्तितोऽर्धम्[14] ॥५८॥
शीघ्रोच्चभुक्तेस्तदपास्य[15] शेषात्
केन्द्रान्त्यजीवाविधिना यदाप्तम् ।
त्रिज्याहतं कर्णविभक्तभेदं
न्यायेन[16] शीघ्रस्य धनर्णमिष्टम् ॥५९॥
तन्मन्दमौर्वीफलचापयुक्तं[17]
सर्वं स्वभुक्तौ[18] धनशोधने तु ।
तस्याविनष्टस्य[19] चलोच्चभुक्ते-
र्जीवाफलं[20] सर्वमनष्टराशौ[21] ॥६०॥

[1] तुक° A, B. [2] बुधभग्वोः···स्वकर्मणा missing from B. [3] स्फुटापेतौ A, B. [4] शुध्येद्व्यत्ययात्तदा साध्यः A, B. [5] °मन्दः सकृत्कर्णः स्वशीघ्रजः A, B. [6] मध्यवशादृणधनं C. [7] व···तातिवक्रगमने C. [8] निपतिताच्छेषं A, B. [9] षड्भिस्तु वक्रे A; षट्भस्तु वक्रे B; षट्चातिवक्रो C. [10] सत् C. [11] त्वेष्यातीतविचारिणोर्विपरकं A, B; नेष्यातीतविचारिणोर्विवरकं C. [12] भुक्तिर्भवेदाहकी C. [13] मन्दान्त्यजीवागुणिका C. [14] वद युक्तितोऽर्धम् A,B. [15] शीघ्रोच्चभक्तेस्तदपास्य A, B. [16] कर्णविभक्तभेदं न्यायेन A, B; कर्ण विभक्तभेद न्यायेन C. [17] °पमुक्ता A; °पमुक्त्वा B. [18] सर्वस्स्वभुक्तौ A; सर्वस्वभुक्तौ B. [19] तस्याविनष्टं स्व C. [20] चलोच्चभक्ते जीवाफलं A, B. [21] सर्वमनिष्ट राशौ A, B.

एवं ग्रहाणां स्फुटभुक्तिरिष्टा[१]
तस्मान्न शुध्येद्यदि शीघ्रलब्धम् ।
तयोर्विशेषः स्फुटभुक्तिसंख्या
वक्री ग्रहोऽसाविति[२] सद्भिरुक्तः ॥६१॥
एवं सुरेड्यार्किधरासुतानां[३]
भुक्तिः स्फुटाऽतो[४] भृगुसोमसून्वोः[५] ।
मन्दोच्चकेन्द्रादपि संस्कृताद्धि
शीघ्रान्त्यजीवाविधिना[६] यदाप्तम्[७] ॥६२॥
तेनैव सर्वेण युतो विहीनो[८]
भोगः स्फुटोऽयं[९] कथितो विशेषः ।
इत्थं[१०] ग्रहाणां व्यवहारिकी स्याद्
भुक्तिः स्फुटासन्नतरा च नित्यम्[११] ॥६३॥
गन्तव्ययाततिथिशेषहते रवीन्द्वो-
र्भुक्ती क्रमेण[१२] दिनभुक्तिविशेषभक्ते[१३] ।
लब्धेन[१४] युक्तरहितौ शशितिग्मरश्मी
ज्ञेयौ समौ सकललोकविधानहेतू[१५] ॥६४॥

इति महाभास्करीये चतुर्थोऽध्यायः ।

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[१] एवं स्फुटा स्याद् ग्रहभुक्तिरिष्टा C. [२] वक्र ग्रहोऽसाविति A, B. [३] सुरेड्यार्कधरासुतानां A; सुरेध्वार्कधरासुतानां B. [४] भुक्तिस्फुटातो C. [५] मृगसोमसून्वोः C. [६] शीघ्राद्यजी° A, B. [७] च लब्धम् A, B. [८] युते विहीनौ A, B; युतोऽथ हीनो C. [९] भोगः स्फुटो यः A, B; भोगस्फुटोऽयं C. [१०] इयं A, B; उक्तं C. [११] भुक्तिः स्फुटासन्नतरा च नित्या A, B; भुक्तिः स्फुटासन्नतरा च नित्यम् C. [१२] भुक्ति क्रमेण A, B; भुक्तिक्रमेण C. [१३] दिनशो भविशेषभक्ते A, B. [१४] भक्तेन B. [१५] °हेतुः A, B.

## पञ्चमोऽध्यायः

भास्वतो ग्रहणं वाच्यमाचार्यार्यभटोदितम् ।
तस्य चादौ विजानीयादुपायानां विनिश्चयम् ॥१॥

पञ्चाष्टभूतरन्ध्रेषुवेदाः कर्णो विवस्वतः ।[१]
सप्तपर्वतरामाब्धिगुणसंख्या निशाकृतः ॥२॥

कलाकर्णहतावेतौ विष्कम्भार्धविभाजितौ ।
स्फुटयोजनकर्णौ तौ सूर्याचन्द्रमसोर्विदुः[२] ॥३॥

दिग्वेदसागरा भानोरिन्दोरितथिहुताशनाः ।
योजनैरुच्यते सद्भिर्भूव्यासः खेषुपङ्क्तयः[३] ॥४॥

विष्कम्भार्धहतौ व्यासौ स्फुटयोजनभाजितौ ।
भवतस्तौ कलाव्यासावुष्णशीतलतेजसोः[४] ॥५॥

नवांशाः पञ्चभोगस्य भूतवर्गांश एव च ।
स्वतुरीयविलिप्ताभिर्युतहीने तनू स्फुटे[५] ॥६॥

सूर्याचन्द्रमसोर्विद्धि राहुबिम्बं च कथ्यते ।
पङ्क्त्यंशश्चन्द्रभोगस्य षोडशांशो विलिप्तिकाः[६] ॥७॥

अथातो मध्यलग्नस्य विधानं सम्प्रवक्ष्यते ।
निरक्षासुभिरुत्पत्तिर्बोद्धव्या शास्त्रकोविदैः ॥८॥

पूर्वाह्णे सूर्ययुक्तस्य गतभागासवो हि ये ।
गन्तव्यानां चापराह्णे[७] भागानामसवः स्मृताः ॥९॥

मध्यतिथ्यन्तरासुभ्यः[८] शोध्या भागादि[९] भास्करे ।
शोध्या देयाश्च भूयोऽपि निरक्षासुवशाद्रवौ ॥१०॥

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[१] पञ्चाष्टरन्ध्रभूतेषुवेदाः कर्णो विवस्वतः A, B; पञ्चाष्टभूतरन्ध्राणि भूतवेदा विवस्त्रतः C. [२] °सोऽस्सदा C. [३] सद्भिर्भुवासः खेषु पङ्क्तिभिः A, B. [४] कलाख्यासा° A, B; °शीतगुतेजसोः A, B, C. [५] °युक्तहीने तनुः स्फुटे A, B; °युतहीने तनूस्फुटम् C. [६] षोटशांशोनलिप्तिकाः A, B. [७] गन्तव्याणां चापराह्णे B; गन्तव्यानामपराह्णे C. [८] मध्यं तिथ्यन्तराशाभ्यः A; मध्यं तिथ्यन्तराभ्यः B. [९] भागाश्च A, B; भागाहि C.

राशयः कालतत्त्वज्ञैरनुपाताप्तमेव च ।
मध्यलग्नमिदं स्पष्टं[1] श्रीमद्भटमुखोदितम् ॥११॥
कक्ष्याभेदाच्छशीभान्वोर्जीवाभेदः[2] प्रकीर्तितः[3] ।
ज्ञापकं च स्वदृक्क्षेप[4] इत्यादिवचनं[5] प्रभोः ॥१२॥
बाहुज्योदयलग्नस्य परक्रान्तिहृता[6] हृता ।
लम्बकेनोदयज्याप्ता कक्ष्यायां भास्वतः स्फुटा[7] ॥१३॥
सैंहिकेयविहीनस्य जीवा लग्नस्य ताडिता ।
तिथिभिश्चन्द्ररन्ध्रैर्कैर्विक्षेपज्या विलग्नजा[8] ॥१४॥
विलग्नक्रान्तिविक्षेपधनुषोस्तुल्यदिक्कयोः[9] ।
युक्तिर्वियुक्तिरन्यत्वे शेषकाष्ठगुणाहतम्[10] ॥१५॥
उदयज्येन्दुकक्ष्यायां व्यासार्धं लम्बकोद्धृतम्[11] ।
राहूनमध्यलग्नाच्च विक्षेपज्या प्रसाध्यते ॥१६॥
मध्यक्रान्तिविषुवज्ज्याकाष्ठयोरेकदिक्कयोः[12] ।
योगो वियोगो वाऽन्यत्वे[13] मध्यज्या शेषदिग्वशात्[14] ॥१७॥
रवेरिन्दोः पलक्रान्तिविक्षेपधनुषां[15] वशात् ।
योगविश्लेषजा जीवा मध्यज्या शेषदिग्भवा ॥१८॥[16]
स्वमध्यज्योदयाभ्यासं विष्कम्भार्धाप्तिवर्गितम् ।[17]
मध्यज्यावर्गतोऽपास्य[18] स्वदृक्क्षेपं[19] पदं विदुः ॥१९॥
गतगन्तव्यनाडीभिर्दृग्ज्या[20] पूर्वोक्तकर्मणा ।
साध्या रवेश्शशाङ्कस्य[21] विधानमिदमुच्यते ॥२०॥

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[1] ......मध्यलग्ना A, B. [2] कक्ष्याभेदाच्छश्चीभावो जीवाभेदः A; कक्ष्याभेदाच्चचीभावो जीवाभेदः B; कक्ष्याभेदाच्छशिभान्वोर्जीवाभेदः C. [3] प्रकीर्त्यते C. [4] ज्ञापनं च स्वदृक्षेपौ A, B. [5] ......त्यादिवचनं B. [6] परत्रास्ति हृता C. [7] भास्वते स्फुटः A. B; भास्वतः स्फुटम् C. [8] पिलग्नजा C. [9] विलग्नक्रान्तिपक्षेवध° B. [10] शेषकाष्ठगुणाज्ज्यागता A, B. [11] लम्बकाहृतम् C. [12] °ज्ज्याताष्टयोरेकदिक्कयोः A, B; °काष्ठयोरेकद्रिक्रयोः C. [13] नानात्वे C. [14] शेषदिशात् B. [15] पलाक्रान्तिविक्षेपधनुषां C. [16] This verse is missing from A, B. [17] स्वमध्योदययाभ्यासाद्विष्कम्भार्धाप्तिवर्गितात् A, B; स्वमध्यज्योदयाभ्यासविष्कम्भार्धाप्तिवर्जितम् C. [18] °तोऽवास्य C. [19] A and B read दृक्षेप in place of दृक्क्षेप. [20] गतगन्तव्यनाडीभिर्भज्यात् A, B. [21] भवेच्छशाङ्कस्य A, B.

समलिप्तेन्दुविक्षेपक्रान्तिज्याचापसंयुतिः ।
वियुक्तिर्विदिशोर्जीवा शेषस्येन्दोरपक्रमः ॥२१॥
तेनाहोरात्रविष्कम्भक्षितिजीवाचरासवः ।
प्रसाध्यास्तैश्च दृग्जीवा गतगन्तव्यकालतः ॥२२॥
स्वदृग्दृग्क्षेपगुणयोर्वर्गविश्लेषजे पदे ।[1]
दृग्गतिज्ये भवेतां ते भास्करामृततेजसोः ॥२३॥
स्वदृग्गतिक्षमाव्यासभेदसंवर्गसंभवम्[2] ।
पृथग्योजनकर्णाप्तं लिप्ताद्यं[3] लम्बनं विदुः ॥२४॥
तद्विशेषो[4] हतः षष्टया स्फुटभुक्त्यन्तरोद्धृतः[5] ।
घटिकादिस्तिथेः[6] प्राक्त्वे शुद्धिः क्षेपोऽपरे[7] मतः ॥२५॥
दिनार्धकालनिष्पन्नं लम्बनं शोध्यते तिथेः ।
उदगिन्दूदयज्यायां दीयते तत्र दक्षिणे ॥२६॥[8]
एवं पुनः पुनः कर्म यावत्तदविशिष्यते ।[9]
तिथिवच्चन्द्रतीक्ष्णांशू सञ्चार्यविव पण्डितैः ॥२७॥
दृक्क्षेपज्ये त्वविशिष्टे[10] भूव्यासार्धहते हृते ।
स्फुटयोजनकर्णाभ्यामवाप्ता लिप्तिकादयः ॥२८॥
अभिन्नाशयोर्विश्लेषस्तासां[11] सूर्यनिशाकृतोः ।
मध्यज्ययोरथान्यत्वे योगोऽवनतिलिप्तिकाः[12] ॥२९॥
दिक् तत्र शशिनो ग्राह्या पातहीनान्निशाकृतः[13] ।
ज्यां खसप्ताश्विभिः क्षुण्णां कलाकर्णेन संहरेत् ॥३०॥
विक्षेपः शशिनः स्पष्टस्तेन युक्ता नतिः स्फुटा ।
नानाशयोस्तु विश्लेषः शेषा सा नतिरुच्यते ॥३१॥[14]
लम्बनान्तरसंयुक्तग्रासमध्याप्तजन्मनोः[15] ।
दृक्क्षेपक्षेपयोः सिद्धा मध्या चावनतिः[16] स्फुटा ॥३२॥

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[1] दृक्क्षेपगुणवर्गस्य विश्लेषपदमाहृतम् C. [2] °संवर्गसञ्चयः C. [3] लिप्ताद्यु A, B; लिप्ताद्या C. [4] तद्विश्लेषो A, B. [5] स्फुटभुक्त्यन्तराहृतः A, B. [6] घटिकादितिथेः A, B; घटिकादिस्थितः C. [7] के वो परे C. [8] This verse is missing from A and B. [9] This hemistich does not occur in A and B. In C the initial word एवं is missing. [10] त्पविश्लिष्टे A, B. [11] अभिन्नाशयो विशेषस्तासां C. [12] योगोपनतिलिप्तिकाः A, B; योगावनतिलिप्तिका C. [13] पातहीनां निशाकृतः C. [14] तातातयोस्तु विश्लेषशेषास्सा गतिरुच्यते A, B. [15] °संयुक्तं ग्रहम° A, B. [16] मध्याद्यवनतिः C.

सूर्येन्दुबिम्बसम्पर्कदलेन सदृशी नतिः ।
ग्रहणं भास्वतो न स्याद्धीनायामस्ति सम्भवः ॥३३॥
सम्पर्कार्धनतिवर्गविशेषपदमाहतम् ।[१]
षष्टचा गत्यन्तरेणाप्ताः[२] स्थित्यर्धघटिकाः स्मृताः[३] ॥३४॥
अविशेषतिथिस्ताभिर्विहीना[४] सहिता सदा[५] ।
ग्रासादिमोक्षकालौ स्तः[६] ताभ्यां जीवाविधिस्तदा ॥३५॥
ग्रासमध्यविनिष्पन्नलम्बनान्तरनाडिकाः ।
स्थित्यर्धे प्रक्षिपेन्नित्यं ग्रहणे[७] तिग्मदीधितेः ॥३६॥
मध्यान्तलम्बनं स्थित्या[८] वर्धते मोक्षसम्भवः ।
स्थित्यर्धमित्यतिस्पष्टमुत्क्षिप्य भुजमुच्यते ॥३७॥
स्पर्शमोक्षौ यदान्यस्मिन्कपाले ग्रहमध्यतः ।
स्पर्शजं लम्बनं सर्वं देयं स्थित्यर्धनाडिषु ॥३८॥[९]
मोक्षेऽप्येवं तदायातं[१०] स्थित्यर्धे दीयते सदा ।
दिनार्धे ग्रासमध्ये च कल्प्यतेऽयं विधिक्रमः[११] ॥३९॥
ग्राह्यग्राहकबिम्बार्धविश्लेषक्षेपवर्गयोः ।
विश्लेषस्य पदं ज्ञेयं विमर्दार्धस्य लिप्तिकाः ॥४०॥[१२]
तीक्ष्णांशुबिम्बवस्वंशलिप्तिकाकालसंयुतः ।
स्पर्शकालो भवेत्सत्यो[१३] भासुरत्वाद्विवस्वतः ॥४१॥
मध्यतिथ्यन्तरासूनामुत्क्रमज्याक्षसङ्गुणा ।
विष्कम्भार्धेन भक्तव्या[१४] लब्धकाष्ठस्य दिग्विधिः ॥४२॥
व्यासार्धादधिकासूनां[१५] क्रमज्यां[१६] त्रिज्यया युताम् ।
कृत्वैवमेव दिक्कल्प्या मध्ये प्राग्ग्रासवद्दिशा[१७] ॥४३॥
उदग्दक्षिणतः प्राह्णे बिम्बप्राक्पश्चिमार्धयोः[१८] ।
नभसः[१९] पश्चिमे व्यस्तमक्षस्य वलनं सदा ॥४४॥

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[१] विष्कम्भार्धनतीवर्गविश्लेषपदमागतम् A, B. [२] षष्टचाहत्यास्तरेणाप्ता A; षष्ठचा हत्या स्तरेणाप्त B. [३] स्फुटा A, B. [४] विशेषस्थितिभिस्ताभिर्विहीना C. [५] तदा A, B. [६] तौ C. [७] प्रक्षिपेन्नित्यग्रहणे C. [८] मध्यान्तलम्बनस्थित्या A, B. [९] स्पर्शनं लम्बनं देयं सर्वस्थित्यर्धनाडिषु A, B. [१०] सदायातं A, B. [११] ग्रहमध्ये च कल्प्यतेऽयं विधिः क्रमात् A, B. [१२] विक्षेपस्य पदाद्देयं विमर्दार्धस्य नाडिकाः A, B. [१३] भवेत्तस्य A, B. [१४] हर्तव्या A, B. [१५] व्यासार्धाच्चाधिकासूनां C. [१६] क्रमज्या A, B. [१७] प्रागासवद्दिशोः A, B; प्रागासवद्दिशा C. [१८] दिग्दक्षिणतः प्राह्णे बिम्बंप्रा° A, B. [१९] नभसं C.

त्रिराशिसहितेन्द्वर्कविपरीतगुणापमः[1] ।
अयनादिक्तु[2] पूर्वार्धे बिम्बस्यैवापरेऽन्यथा ॥४५॥
नानाशयोस्तयोर्विद्धि विश्लेषः धनुषोः सदा[3] ।
संयोगोऽन्यत्र तज्जीवा सम्पर्कार्धहता[4] हृता ॥४६॥
विष्कम्भार्धेन यल्लब्धमाशासाम्ये युतं[5] नतौ ।
विश्लेषो व्यत्यये[6] कार्यो वलनं तत्र शिष्यते ॥४७॥
मुखविन्यस्तसुश्लक्ष्णवर्तिकाङ्कुरशोभिना ।*
अङ्किताङ्गुलतद्भागसमस्निग्धोरुमूर्तिना[8] ॥४८॥
ग्राह्यबिम्बार्धमानेन[9] कर्कटेनालिखेत्क्षितौ ।
ग्राह्यग्राहकबिम्बार्धसमवक्त्रेण चापरम् ॥४९॥
पूर्वापरे[10] ततः कुर्यान्मीनेनोत्तरदक्षिणे ।
दक्षिणोत्तरतः केन्द्रान्नीत्वा वलनमप्यतः[11] ॥५०॥
उत्पाद्य तत्र मत्स्याङ्कं[12] युक्त्या सूत्रं नयेद् बुधः ।
बाह्यमण्डलतत्सूत्रसम्पाते बिन्दुनिश्चयः ॥५१॥
बिन्दुतः केन्द्रसम्प्रापि[13] सूत्रं तस्मात्[14] प्रसार्यते ।
तस्यग्राह्यपरिधेश्च सम्पातो[15] यत्र लक्ष्यते ॥५२॥
तत्र तीक्ष्णांशुबिम्बस्य प्रदेशौ[16] स्पर्शमोक्षयोः ।
मौरिकाऽर्धाङ्गुला[17] ज्ञेया यथा वा लक्ष्यते दिवि ॥५३॥
नत्यसंयुक्तविश्लिष्टं वलनं[18] ग्रहमध्यजम् ।
तन्नत्योस्तुल्यकाष्ठत्वे वलनं पूर्वतो नयेत् ॥५४॥

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[1] °वमः A, C. [2] लग्नाद्या दिक्तु A, B. [3] विश्लेषधनुषोस्तयोः A, B; विश्लेषधनुषोः सदा C. [4] सन्वर्कार्धहता A, B. [5] °साम्य-युते C. [6] व्यत्ययः C. * Verses 47-48(i) are missing from A and B. [8] अन्तिकाङ्गुलतद्भाग° A, B; °धोऽथ मूर्तिना C. [9] ग्राह्याङ्गुलार्धमानेन A, B. [10] पूर्वावरे B; पूर्वापर C. [11] बलमानतः C. [12] उत्पाटय तत्र मत्स्यान्तं A, B;.. उत्पाद्य मत्स्याङ्कं C. [13] विन्दुतः केन्द्रसम्प्राप्ति A, B. [14] सूत्रं तस्मात्प्रसाध्यते A, B; तस्मात् सूत्रं प्रसार्यते C. [15] तस्य ग्राह्यपरिधेश्च सन्तापो A; तच्च ग्राह्यपरिधेश्च सम्पातो C. [16] प्रदेशः A, B. [17] मौर्वी कार्धाङ्गुला A; मौर्वीकार्द्धाङ्गुला B. [18] नत्या संयुक्तविश्लिष्टं वलनं A, B; नत्यसंयुक्तविश्लिष्टवलनं C.

भिन्नाशयोस्तयोः केन्द्रात् पश्चिमेन प्रसार्यते ।
तन्नत्यनुदिशं सूत्रं ततो मत्स्येन नीयते ॥५५॥
बाह्यमण्डलतः केन्द्रमानयेत्तद्विचक्षणः[१] ।
केन्द्रात्तदनुसारेण नतिसूत्रं प्रसार्यते ॥५६॥
मध्यबिन्दुस्तदग्रे[२] स्याद्बिन्दू तौ[३] स्पर्शमोक्षयोः ।
दक्षिणस्यां नतौ भागे याम्ये सौम्ये विपर्ययः[४] ॥५७॥
विधिर्ग्रहणमध्यस्य भानोरिन्दोर्विपर्ययात्[५] ।
आलिखेत्तद्ग्रहे व्यक्तं ग्रासमध्यान्तसम्भवम्[६] ॥५८॥
मध्यबिन्दुशिरोन्यस्तग्राहकार्धवपुर्धृता[७] ।
खण्डयेत् कर्कटेनाशु निर्दिष्टस्पष्टमानतः[८] ॥५९॥
ग्राह्यस्य खण्डितं यावच्छेद्यके लिखितं च यत् ।[९]
ग्रहमध्ये तथा सर्वं[१०] विस्पष्टमुपलक्ष्यते ॥६०॥
न्यस्तबिन्दुत्रयप्रापि[११] मीनाभ्यां वृत्तमालिखेत् ।
ग्राहकस्य भवेत्पन्थाः तत्रेष्टग्रासकल्पना ॥६१॥
इष्टकालविहीनेन[१२] स्थित्यर्धेन हतं[१३] हरेत् ।
सूर्येन्द्वोर्भुक्तिविश्लेषं षष्ट्या लब्धस्य[१४] वर्गितम् ॥६२॥
प्रक्षिप्यावनतेर्वर्गे यन्मूलं रविसोमयोः ।
इष्टग्रासशलाका स्यात् तच्छेषो[१५] ग्रास इष्टजः ॥६३॥
सुश्लक्ष्णा वैणवी शलाका[१६] केन्द्रात्तिर्यक् प्रसार्यते ।
तस्याग्रेण[१७] तथा पन्थाः प्राप्यते[१८] ग्राहकस्य यः[१९] ॥६४॥
तत्र[२०] ग्राहकमानेन खंडयेद् ग्राह्यबिम्बकम् ।
तावदेव तथाग्रस्तं[२१] दृश्यते ग्राह्यमण्डलम्[२२] ॥६५॥

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[१] केन्द्रमानीयेत्तद्विचक्षणः A. [२] मध्यबिन्दु° C. [३] स्याद्बिन्दुस्तत् A, B. [४] विपर्ययात् A, B. [५] भानोरिन्दोश्च पर्ययात् A, B. [६] °सम्भवैः C. [७] °पुर्युता C. [८] °स्फुट मानता A, B. [९] ग्राहास्य खण्डिता यावच्छेद्यतेऽथ······यत् A; ग्राह्यस्य खण्डिता यावच्छेद्यतेऽथ यत् B. [१०] सर्वा A, B. [११] न्यस्तं बिन्दुत्रयप्राप्ति A, B. [१२] इष्टहीनेन युक्तेन A, B. [१३] हतां A, B; नतं C. [१४] लम्बस्य C. [१५] स्याच्छेषो B; न्धात्तच्छेषं C. [१६] वैर्णविशत्कात् A, B; वैणवी शलाका C. [१७] यथाग्रेण C. [१८] प्रोच्यते A, B. [१९] च A, B. [२०] यत्र A, B. [२१] यथावक्रं C. [२२] ग्राह्यमण्डले A, B.

विमर्दार्धकलाहीनं यत् स्थित्यर्धं कलामितम्[1] ।
तत्कालच्छेद्यकस्तेन भास्वद्बिम्बं विखण्डयेत् ॥६६॥[2]
प्रदेशस्तस्य[3] बिम्बस्य कर्कटेनावगाह्यते ।
पश्चार्धे गृह्यते व्यक्तं पूर्वे चासौ प्रमुच्यते ॥६७॥
एवमाशामुखादर्शसकलोरुकलाभृतः ।
कान्तावदनसंवृत्तवपुषः[4] शशलक्ष्मणः ॥६८॥
अपि कार्यो[5] विधिर्ज्यानां विशेषो यः स कथ्यते ।
भूच्छायाया गुणाः[6] कल्प्या रवेः कक्ष्यासमुद्भवाः ॥६९॥
भागहारः शशाङ्कस्य कर्ण एव प्रकीर्तितः ।
शशिवल्लम्बनाल्लब्धं व्यत्ययात् क्षेपशोधने ॥७०॥
ताडितो योजनः कर्णो धात्रीव्यासेन[7] भास्वतः ।
तयोर्व्यासविशेषेण भूच्छायादैर्घ्यमाप्यते[8] ॥७१॥
पञ्चाहतो रवेः कर्णः षोडशापहृतः[9] फलम् ।
भूच्छायादैर्घ्यमाख्यातमिन्दुकर्णस्ततः क्षयः ॥७२॥
भूव्यासगुणिते शेषे छायादैर्घ्यहृते फलम् ।
विष्कम्भार्धहृतं भक्तं चन्द्रकर्णेन तत्तमः[10] ॥७३॥[11]
अन्ये वदन्ति[12] शशिनो ग्रहणोपदेशं
हीनं गुणैर्दशभिरल्पफलान्तरत्वात्[13] ।
स्थित्यर्धकालमचलं विदधीत तस्मिन्
आद्यन्तयोर्ग्रहणमध्यसमुत्थितं यत् ॥७४॥
क्षुण्णा[14] स्थित्यर्धकालेन भुक्तिः षष्टया[15] समाहृता ।
समलिप्ते क्षयः स्पर्शे[16] मोक्षे क्षेपो निगद्यते ॥७५॥
विक्षेपस्तस्य तस्माच्च[17] स्थित्यर्धं च प्रसाध्यते ।
एवं कर्माविशेषोऽयं[18] विमर्दार्धस्य वा पुनः ॥७६॥

[1] कलाभृतः A, C; कलाभितः B. [2] तत्कालच्छेद्यकं तेन भास्वत्खण्डादि खण्डयेत् A, B. [3] प्रदेशसूत्रं A, B. [4] °संवृतः वपुषः B. [5] अविकार्यो A, B. [6] भूच्छायायां गुणाः A, B; भू······छाया रवेः C. [7] धात्रिव्यासेन B. [8] छायादीर्घत्वमाप्यते C. [9] षड्वशापहृतः C. [10] तततः A, B. [11] In C the second half of this verse reads as follows विष्कम्भार्धहृतं चन्द्रकर्णेन·········तत्तमः [12] भवन्ति A, B. [13] °रन्यफ° A, B. [14] क्षुण्णः A. [15] षष्ठ्या B. [16] क्षयस्पर्शे A, B, C. [17] तस्मिंश्च C. [18] कर्माविशेषोऽयं A, B.

विक्षेपः शशिनः कल्प्यश्छेद्यकाले सतां वरैः ।
उत्तरो दक्षिणे नित्यं दक्षिणश्चोत्तरे तथा ॥७७॥
प्रोक्तमेतदवधूय मत्सरं[1]
सूर्यचन्द्रतमसां क्रमागतम् ।
कर्म येन विदुषा समर्जितं[2]
दैवविद्भवति सर्वतन्त्रवित् ॥७८॥

इति महाभास्करीये पञ्चमोऽध्यायः ।

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[1] मत्सरः B; यत्परं C. [2] समर्पितं A, B, C.

## षष्ठोऽध्यायः

स्वेष्टदेशपलजीवया हतां
क्षिप्तिमिष्टशशिजां[1] समाहरेत्[2] ।
लम्बकेन यदवाप्तमुत्तरे
शोधयेदुदयगे निशाकरे ॥ १ ॥
अस्तगे धनमुशन्ति तद्विदो[3]
दक्षिणे विधिरयं विपर्ययात्[4] ।
वर्जितत्रिभवनस्य[5] शीतगो-
रुत्क्रमापमविसंहृतिं[6] हरेत् ॥ २ ॥
व्यासवर्गनिचयेन शोधये-
च्चन्द्रतोऽयनविमण्डलाशयोः[7] ।
तुल्ययोर्धनमुशन्ति तद्विदो
व्यत्यये[8] शशिनि तत्फलं[9] सदा ॥ ३ ॥
दृश्यचन्द्र इति कथ्यते बुधै-
रेवमाकलितचारसञ्चयः[10] ।
भास्करेन्दुविवरांशकोद्भव-
प्राणराशिघटिकाद्वये[11] शशी ॥ ४ ॥
दृश्यतेऽमलनिरभ्रतारके
भास्करेऽस्तगिरिमूर्धगेऽम्बरे ।
चन्द्रभानुविवरोत्क्रमज्यया
चन्द्रबिम्बमभिहत्य भाजयेत् ॥ ५ ॥
षण्णगाष्टरससंख्यया[12] सितं
नित्यमेव गणकाः प्रजानते[13] ।

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[1] शिप्तिमिष्टशशिजां C. [2] हेरेत्पुनः A, B. [3] ता रवेः A, B. [4] विपर्ययः A,B. [5] वर्जितं त्रिभुवनस्य A, B, C. [6] रुत्क्रमावमविसंहृतिं A; रुत्क्रमावम···संहृतिं C. [7] च्चन्द्रमोऽय° C. [8] व्यत्ययेन B. [9] तत्पलं A. [10] °मालिखित° A, B. [11] भास्करेन्दुविवरांशकोद्भवः प्राणराशिघटिकाद्वयैः A, B. [12] षण्णवाष्ट° A, B. [13] प्रजायते A, B.

चन्द्रभानुविवरं[1] पदाधिकं[2]
स्यात्तदा क्रमगुणेन युक्तया[3] ॥ ६ ॥
त्रिज्यया[4] सितविधिर्विधीयते
पौर्णमास्यपरतोऽसितं[5] तथा ।
सूर्यचन्द्रविवरांशजीवया
चोत्क्रमक्रमवशात्सितं विदुः ॥ ७ ॥
चन्द्रमोपमविकाष्ठयोर्युति-[6]
स्तुल्यगोलभवयोरतोऽन्यथा ।
काष्ठयोर्विवरतोऽपमो[7] गुण-
स्तेन चन्द्रचरनाडिकाविधिः ॥ ८ ॥
भानुचन्द्रविवरासुभिः सदा
शङ्कुरुक्तविधिना विधीयते ।[8]
अक्षचापगुणसंगुणं हरे-
ल्लम्बकेन शशिकीलकं स्फुटम् ॥ ९ ॥
कीलकाग्रगुण आप्यते ततो
नित्यदक्षिणगतोऽस्तसूत्रतः ।
गोलखण्डगुणितो[9] विभज्यते
लम्बकेन शशिनोऽपमः स्फुटः[10] ॥१०॥
दक्षिणोत्तरदिशोर्निशाकृतो[11]
लभ्यतेऽग्रगुणसंज्ञितः[12] सदा ।
तुल्यकाष्ठगतयोस्तयोर्युतिं[13]
शुद्धिमन्यभवयोस्तयोर्विदुः[14] ॥११॥
भास्कराग्रगुणकेन तस्य तु
व्यत्ययेन युतिशोधने कृते ।

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[1] भानुचन्द्रवि° C. [2] वदाधिकं A, B. [3] युक्त्या B. [4] त्रज्यया B. [5] पूर्वमानवसतोसितं A; पूर्वमानवरतोसितं B. [6] चन्द्रमाबदवि° A, B; चन्द्रमोऽवम° C. [7] काष्ठयोर्विवरजापरो A, B; काष्ठयोर्विवरतोऽवमो C. [8] In B, 8(ii) and 9(i) have been interchanged. [9] गोलखण्डगुणिते C. [10] शशिनोपमा स्फुटः A, B; शशिनोऽवमस्फुटा C. [11] °कृतोः A, B. [12] लभ्यते ग्रहण संज्ञितः C. [13] °युतिः A, B, C. [14] शुद्धिरग्रहणयोरतोऽन्यथा C.

बाहुकः शशभृतः स्फुटो मतः[1]
कोटिरत्र शशिशङ्कुरिष्यते ॥१२॥
सूर्याद्याम्योत्तरे बाहुः कोटिः[2] पूर्वापरायता[3] ।
बाहुकोटिशिरःप्रापि सूत्रं कर्णः प्रकीर्तितः ॥१३॥
कर्णकोटयग्रसम्पाते शशिबिम्बं समालिखेत् ।
तस्य पूर्वापरं[4] कर्णस्तन्मध्याद्दक्षिणोत्तरे ॥१४॥
दक्षिणोत्तरयोर्बिन्दू चन्द्रबिम्बे समालिखेत् ।[5]
कर्णसूत्रानुसारेण बिम्बान्तस्सिसितबिन्दुकम्[6] ॥१५॥
तद्विन्दुत्रयशीर्षस्पृग्वृत्तमालिख्यते[7] सदा ।
तत्र शीतांशुबिम्बस्य विवरं[8] शौक्ल्यमुच्यते ॥१६॥
शृङ्गोन्नतिनती साम्यं मानादिष्टं[9] यथा तथा ।
तत्सर्वं व्योम्नि शीतांशोर्विस्पष्टमुपलक्ष्यते[10] ॥१७॥
अस्तारूढे[11] रवावेतदिष्टकालेऽस्तलग्नतः ।
तत्कालेन्दोस्तु दृग्ज्यादिकर्म सर्वं प्रकीर्तितम् ॥१८॥
अष्टम्याः परतः कल्प्यो लग्नमेव दिवाकरः ।[12]
शङ्क्वादिको विधिस्तेन सितमानविवर्जितः[13] ॥१९॥
अर्केन्दुविवरप्राणैरुदयास्तेन्दुवैवरैः ।
शङ्कुः कालवशात्कार्यो नाविशिष्टैर्यथेष्टजैः ॥२०॥[14]
एवमास्तमिकैस्तैस्तैर्भास्करेन्दुतमोमयैः[15] ।
यावत्पञ्चदशी तावत् कर्मेदं शशिनः स्मृतम्[16] ॥२१॥
रविचन्द्रान्तरा नाड्यो[17] दिनमानेन वर्जिताः[18] ।
प्राक् पश्चाद् दृश्यते सोमस्तावतीभिरिनेऽस्तगे ॥२२॥

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[1] बाहुका शशभृतः स्फुटा मता C. [2] कोटी C. [3] पूर्वंपरायतः A, B. [4] पूर्वापर C. [5] The second half of verse 14 and the first half of verse 15 is missing from A and B both. [6] बिम्बादसितबिन्दुतः C. [7] तदिन्दुद्वय° C. [8] विवरः A, B. [9] शृङ्गोन्नती नतीसाम्ये मानादिष्टां A, B; शृङ्गानाती नतीसाम्यमानादिष्टं C. [10] °मुपलभ्यते A, B. [11] अस्तारूढ C. [12] The first half of verse 19 is missing from C. [13] धनमानविवर्जितः A, B. [14] अथेन्दुविवरप्राणैरुदयस्थे रवेः परैः । शङ्कून्नतिवशात्कार्यो नावशिष्टे यथेष्टजम् ॥ A, B. [15] °न्दू तमोमयैः A, B; °स्तैस्तै······भास्करेन्दु° C. [16] शशिनो मतम् C. [17] रविचन्द्रान्तरं नाड्योः A, B; रविचन्द्रान्तरनाड्यो C. [18] वर्धिताः C.

पक्षान्तात्परतः[1] सोमो हरिजादुपरि[2] स्थितः ।
इष्टकालविलग्नोत्थैः[3] प्रमाणैः परिलिख्यते ॥२३॥
कोटिः पूर्वाग्रतः[4] कार्या भुजा याम्योत्तरायता ।
अग्रे कोटिशिरःस्पृक्कं[5] कर्णसूत्रं प्रसार्यते ॥२४॥
पूर्वतः कर्णसूत्रेण सितमानं प्रवेशयेत् ।
असितं[6] वा पराद्भागं[7] शीतांशोः परिलेखने ॥२५॥
अथवाऽर्कोदये कार्यं तत्कालेन्द्वर्कसम्भवैः ।
सितासितस्य पूर्वोक्तं दृश्यकालोऽभिधास्यते[8] ॥२६॥[9]
षड्राशियुक्तसूर्येन्दुवैवरादुदयासवः[10] ।
अविशिष्टाः सिते पक्षे दृश्यकालोऽप्यतः परम्[11] ॥२७॥
चक्रार्धयुततीक्ष्णांशोश्चन्द्राच्च करणागतात्[12] ।
अविशेषान्तरप्राणैर्निशीथे दृश्यते शशी ॥२८॥
अस्तकालविलग्नेन्द्वोरन्तरप्राणजन्मना[13] ।
कालेन लग्नशीतांशू[14] कृत्वा भूयोन्तरासवः ॥२९॥
पूर्वकालेन ते योज्याश्चन्द्रे[15] लग्नाधिकेऽथवा[16] ।
विश्लेषो वाऽन्यथा यावत्तुल्यकालोदयेन्दवः[17] ॥३०॥
इत्थं कर्मक्रमावाप्तकालेनामृततेजसः ।
रश्मिभिः पूरयन्नाशां निशीथे दृश्यते शशी ॥३१॥
अस्ताद्रिमस्तकारूढतिग्मांशुमतभागतः ।
स्वदेशे भोदयप्राणा[18] ग्राह्या यावन्निशाकरम्[19] ॥३२॥
तेष्वहर्मानशुद्धेषु रात्रौ[20] व्युष्टेषु चन्द्रमाः ।
दृश्यते त्वविशिष्टेषु[21] तस्मात्तानविशेषयेत्[22] ॥३३॥

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[1] पक्षान्तात्परितः A, B; पक्षात्परतः C. [2] हरिमादुपरि A, B. [3] इष्टकालविलग्नोक्तैः C. [4] पूर्वगता A, B; पूर्वाश्रितः C. [5] तदग्रे कोटिशिरःस्पृक् C. [6] अन्वितं A, B. [7] वापरभागात् C. [8] °ऽभिधार्यते A, B. [9] Verse 26 is missing from C. [10] °वैपरादोदयासवः A, B; °वैवराभोभयासवः C. [11] दृश्यकायोस्यतं वरम् A, B; दृश्यकालोच्युतःपरम् C. [12] चरणागतात् C. [13] °विलग्नेन्दो° C. [14] कालोन लग्नशीतांशोः C. [15] योज्याश्चन्द्र C. [16] °केरवौ A, B. [17] °येनवः A, B. [18] देशभेदोदयाप्रणा A, B. स्वे स्वे शोभोदयप्राणा C [19] यावन्निशाकृतः A; यावन्निशाकृताः B. [20] रात्रे C. [21] परिशुद्धेषु A. B. [22] तस्मात्तानपि शेषयेत् C.

तद्घटीभोगसंयुक्तसूर्येन्द्वन्तर्घटीक्रमात्[1] ।
ततोऽहर्मानसंशुद्धिः शेषभोगादिकर्मणा ॥३४॥
अर्केन्दुमध्यनाडीभ्यो[2] दिनमानं विवर्धते ।
तद्विशेषघटीशेषे दिवा चन्द्रोदयः स्मृतः ॥३५॥
तन्नाडिकानुपाताप्तभोगहीनार्कचन्द्रयोः ।
अन्तरालोदयप्राणैः कल्प्यं तत्राविशेषणम् ॥३६॥[3]
चन्द्रादौदयिकात्प्राणा[4] यावानौदयिको[5] रविः ।
ग्राह्यास्ततोऽपि विश्लेषात् कल्प्यते निश्चलकिया ॥३७॥
कृताविशेषनाडीभिर्यावन्नोदेति[6] भास्करः ।
तावदाशामुखादर्शः प्राणैराक्रमते शशी ॥३८॥
आसन्नौ स्वधियाऽभ्यूह्य[7] मध्यलग्ननिशाकरौ ।
कालेन्दुमध्यलग्नानामविशेषं समाचरेत् ॥३९॥
नाड्योऽन्तरालजाः[8] साध्या लङ्काराश्युदयैस्तयोः[9] ।
ऊने[10] विश्लेषनाडीभ्यः[11] शुद्धिः क्षेपोऽधिके स्मृतः ॥४०॥
मध्यलग्नसमश्चन्द्रो जायतेऽनेन कर्मणा ।
तत्क्षिप्त्यपक्रमाक्षैस्तु[12] मध्यच्छाया प्रसाध्यते ॥४१॥[13]
अर्धोदितस्य चन्द्रस्य तथाऽर्धास्तमितस्य च ।
इन्दूदयास्तलग्नाग्रेः शृङ्गस्योन्नतिकल्पना[14] ॥४२॥
कर्मेदं शशिनस्तस्य कुर्यादमृतदीधितेः ।
ग्रहाणामपि सर्वेषामिदं कर्म विधीयते ॥४३॥
अंशैरन्तरितः सूर्यान्नवभिर्दृश्यते भृगुः ।
द्व्यधिकैर्द्व्यधिकैर्दृश्या ज्यौज्ञसौरिधरासुताः[15] ॥४४॥
प्रपन्नवक्रः[16] सद्वर्त्मा सितो दृश्योऽर्धपञ्चमैः[17] ।
चतुर्भिर्वांशुमालित्वादंशैरंशुमतोऽन्तरैः ॥४५॥

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[1] °संयुक्तः° A, B. [2] अर्केन्दुमध्यनाडिभ्यो A; अर्केन्दुभोगनाडिभ्यो B. [3] The second half of verse 36 is missing from C. [4] चन्द्रादौदयितात्प्राणा B; चन्द्रादौदयिकाः प्राणा C. [5] द्यावानौदयिको A, B. [6] कृतावशेषनाडी° A, B; कृताविशेन्नाडी° C. [7] आसन्नस्वधिया ह्यत्र A, B. [8] नाड्योन्तरालजैः A, B; नाड्योऽन्तरा भुजाः C. [9] लङ्कोरा° C. [10] ऊना C. [11] शुद्धि A, B. [12] तत्क्षित्याप° A, B. [13] Verse 41 is missing from C. [14] शृगस्यो° A, B. [15] ज्योज्ञसौरिधरासुताः A, B; ज्ञार्कसौरिधरासुतान् C. [16] प्रपन्नदृश्यः A, B; प्रसन्नवक्त्रः C. [17] सतोदृश्येऽर्ध° C.

कालभागाः क्रमेणैते दिग्घ्ना[1] विघटिकाः[2] स्मृताः ।
ऐन्द्रयां[3] तद्राशिजा ज्ञेया वारुण्यां सप्तमस्य तु[4] ॥४६॥
ग्रहसूर्यान्तरांशघ्नं[5] त्रिंशता स्वोदयं हरेत् ।
लब्धकालो निरुक्तेन यदा तुल्यस्तदोदयः[6] ॥४७॥
मन्दोच्चकर्णगुणितं[7] शीघ्रकर्णं विभाजयेत् ।
विष्कम्भार्धेन संलब्धो भागहारः प्रकीर्तितः ॥४८॥
ग्रहयोरन्तरं भाज्यं प्रतिलोमानुलोमयोः ।
भुक्तियोगेन शेषाणां भोगविश्लेषसंख्यया[8] ॥४९॥
दिनादिर्लभ्यते[9] कालो योगिनां योगकारकः ।
भुक्तेरनेकरूपत्वात् स्थूलः कालोऽत्र गम्यते[10] ॥५०॥
समलिप्तौ ततो[11] युक्त्या कुर्यात्तन्त्रस्य वेदिता ।
स्वोपदेशाद्गुरोर्नित्यमभ्यासेनापि गम्यते ॥५१॥[12]
पातभागविहीनस्य[13] समलिप्तस्य जीवया[14] ।
हत्वा सदा स्वविक्षेपं[15] भागहारेण भाजयेत् ॥५२॥
जीवभौमार्कपुत्राणामेवं[16] विक्षेपकल्पना ।
शीघ्रोच्चाच्छेषयोश्चापि विक्षेपो दक्षिणोत्तरः[17] ॥५३॥
भिन्नदिक्कौ तु विक्षेपौ युक्तावन्तरमिष्टयोः[18] ।
तुल्यदिक्कौ विशेषेण[19] विद्याद्विवरलिप्तिकाः[20] ॥५४॥
पादाङ्गुलकलाद्धर्द्धा यथा[21] वा लक्ष्यते दिवि ।
तदन्तरं तयोर्वाच्यं योगिनां योगकोविदैः ॥५५॥
द्वात्रिंशत्पञ्चभिर्हृत्वा भूयो भूयस्तदुत्तरैः ।
शुक्रज्यौज्ञार्किभौमानां[22] व्यासलिप्ताक्रमं विदुः ॥५६॥

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[1] द्विघ्ना A; दि···C. [2] पिघटिकाः B. [3] ऐन्द्रं A, B. [4] सप्तमं स्मृतम् A, B. [5] ग्रहसूर्यान्तरांशघ्नात् A; ग्रहसूर्यान्तरांशघ्ना B. [6] तुल्यस्तयोदयः A. [7] °गुणितः A. [8] भुक्तवि° A, B. [9] दिनादि लभ्यते C. [10] स्थूलस्सम्यग्गते···C. [11] समलिप्तावतो C. [12] सोपदेशदाद्गुरोर्नित्यमभ्यासं वावगभ्यते C. [13] वात° A, B. [14] निश्चयात् A, B. [15] सभास्वविक्षेप A, B; सदास्य विक्षेपं C. [16] जीवभौमार्किपुत्राणामेवं A, B. [17] दक्षिणोत्तरे C. [18] यत्ता° C. [19] तुल्यदिक्कौ तु विश्लिष्टौ C. [20] विद्याद्विपरलिप्तिका C. [21] वदाङ्गुलकलार्धार्धाद्यथा A, B; पादाङ्गुलकलाद्धा···यथा C. [22] शुक्रज्योग्ज्ञार्किभौमानां A, B; शुक्रज्ञार्कार्किभौमानां C.

एतैरेव हतः[1] कर्णश्चन्द्रयोजनजः[2] क्रमात् ।
लम्बनादिषु हारः स्यान्मानयोजनमाश्रितः[3] ॥५७॥
विष्कम्भार्धेन हर्तव्या[4] भागहारहताः स्फुटाः ।
भागहारहृता व्यासा[5] व्यासार्धघ्नाश्च लिप्तिकाः ॥५८॥[6]
शेषः[7] शीतांशुवत्कार्यो दशजीवाविनिश्चयः[8]॥
चन्द्रोदयोपदेशेन[9] शङ्कुः स्यात् स्वचरादिभिः ॥५९॥
स्वहारैर्ग्रहयोगेषु[10] लम्बनावनती विदुः[11] ।
ग्रहोपरागवच्छेषं स्थित्यर्धादिविधिक्रमः ॥६०॥
इति प्रतिदिनाभ्यासविमलीकृतचेतसाम्[12] ।
गुरुप्रसादसम्प्राप्तशास्त्रसद्भावचक्षुषाम्[13] ॥६१॥
नान्यथा जायते वाणी ग्रहचारानुयायिनी[14] ।
रम्यानुरक्तकान्तायाश्चित्तवृत्तिरिवामला ॥६२॥

इति महाभास्करीये षष्ठोऽध्यायः ।

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[1] एतैरपहृतः A, B; एतैरेव C. [2] °योजनताः A, B; °योजनतां C. [3] योजन is missng from C. [4] भक्तव्या C. [5] लिप्ता C. [6] The second half of verse 58 is missing from A, B. [7] शेष C. [8] विनिश्चयम् C. [9] चन्द्रोदयोपदेशौ तु A, B. [10] स्वभागहारैर्वा वारे C. [11] बन्धनावनतिर्विदुः A, B; लम्बेनावनतीविदुः C. [12] °चेतसः A, B. [13] गुरुःप्र° B. [14] पाणिग्रहचारानुयायिनि A, B.

## सप्तमोऽध्यायः

शतमष्टोत्तरं भानोश्चतुर्भिरयुतैर्हतम्[1]
इन्दोः षट्त्र्यग्निरामेषुभूभृन्नगशिलीमुखाः[2] ॥१॥
सागरर्त्विषुषड्वेदशीतरश्मिसमाः[3] शनेः[4] ।
वेदाश्विद्विचतुष्षट्करामाः सूरेरसृक्तनोः ॥२॥
कृतद्व्यष्टर्तुरन्ध्रद्वियमला[5] भास्करस्य ये ।
बुधभृग्वोस्तु शेषाणां शीघ्रोच्चभगणाः स्मृताः ॥३॥
इन्दूच्चस्य नवैकाश्विवस्वष्टकृतसंज्ञिताः[6] ।
बुधस्य खाश्विखाद्र्यग्निरन्ध्राचलनिशाकराः[7] ॥४॥
भृगोर्वस्वष्टरामाश्विद्विखसप्तसमा[8] गणाः[9] ।
राहोः षड्द्विकनेत्राश्विविष्णुक्रमयमाः[10] स्मृताः ॥५॥
अङ्गपुष्कररामाग्निरन्ध्रेष्विन्दुमिताऽधिकाः ।
द्वादशघ्नं युगं भानोर्भागहारोऽधिकाप्तये ॥६॥[11]
अवमा व्योमवस्वक्षद्व्यष्टखेष्वश्विनो गणाः ।[12]
खाष्टव्योमाभ्रखाभ्राग्निखाष्टयो[13] हार इष्यते ॥७॥
व्योमखेष्वद्रिशीतांशुरन्ध्राद्र्यद्रीषुचन्द्रकाः[14] ।
युगस्य दिवसाः प्रोक्ता विक्षेपांशास्ततः परम् ॥८॥
बुधास्फुजिद्रविजानां[15] द्वावेको वचसां पतेः ।
सार्धोऽशः[16] क्षितिपुत्रस्य पातभागाः क्रमेण च ॥९॥

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[1] भानोश्चतुर्भिरयुतैर्हृतम् A, B. [2] °भूभृन्नागशिलीमुखाः A; °भूभृन्नगतिलिखामुखाः B; °भृगून्नगशिलीमुखाः C. [3] सागरं चीषु° A, B; सागरर्तुंषु° C. [4] शनैः C. [5] कृत-द्व्यष्टर्तुरन्ध्राद्वियमला C. [6] °संज्ञितः A, B. [7] °द्यग्निरन्ध्राकरनिशाकराः C. [8] खभृ-गोर्वस्वष्टरामाश्वि° A, B; भृगोर्वस्वष्टराशिद्वि° C. [9] गुणाः A, B, C. [10] °नेत्राग्निविष्णु क्रममिताः A, B. [11] द्वादशघ्नयुतं भानोर्भङ्गहाराधिकाप्तयोः A; द्वादशघ्नयुतं भानोर्भंगहारोधिकाप्तयोः B. [12] अवमाख्योऽवमस्वक्षद्व्यष्टखेष्वश्विनो गणाः A; अवमारव्योमस्त्रक्षद्व्यष्टखेष्ठश्विनो गणाः B. [13] खाष्टव्योमाभिखाभ्राग्निखाष्टयो A, B; खाष्टव्योमाभ्रखाभ्रानलाष्टयो C. [14] °चन्द्रखाः A. [15] बुधस्फुजिभ्रविणां च A, B. [16] साधींश: A; साधींशः B.

विंशतिः खरसाश्चापि शतं खाष्टौ खसागराः ।
उदगाशादिविक्षेपान्[1] पातहीनाद् विनिर्दिशेत् ॥१०॥
आशाश्विनः खरन्ध्राणि[2] रसविष्णुक्रमाश्विनः[3] ।
खाष्टेन्दवोऽष्टरुद्राश्च मन्दोच्चांशा[4] यथाक्रमम् ॥११॥
भास्करस्य विजानीयादष्टसप्ततिमंशकान्[5] ।
स्वमन्दोच्चं ग्रहाच्छोध्यं शीघ्राच्छोध्या ग्रहाः[6] सदा ॥१२॥
सप्त चत्वारि रन्ध्राणि पर्वता मनवः क्रमात् ।
एकत्रिंशन्नवशरा नव चाष्टिस्त्रिकेषवः[7] ॥१३॥
मन्दशीघ्रोच्चवृत्तानि विद्याद् विषमयोरपि[8] ।
समयोः पदयोश्चापि[9] कथ्यन्ते मन्दशीघ्रयोः ॥१४॥
शिलीमुखाश्विनोऽग्न्येकवसवोऽष्टादशैव[10] च ।
नवाश्विनो नगशरा[11] वसवस्तिथयः क्रमात् ॥१५॥
एकपञ्चाशतं[12] चैव सूर्याचन्द्रमसोरतः[13] ।
विष्णुक्रमः क्षितिधरा[14] जीवा मख्यादयो मताः ॥१६॥
मख्यादिरहितं कर्म[15] वक्ष्यते[16] तत्समासतः ।
चक्रार्धांशकसमूहाद्विशोध्या[17] ये भुजांशकाः ॥१७॥
तच्छेषगुणिता[18] द्विष्ठाः शोध्याः खाभ्रेषुखाब्धितः[19] ।
चतुर्थांशेन शेषस्य द्विष्ठमन्त्यफलं[20] हतम् ॥१८॥
बाहुकोट्योः[21] फलं कृत्स्नं क्रमोत्क्रमगुणस्य वा ।
लभ्यते चन्द्रतीक्ष्णांश्वोस्ताराणां वापि तत्त्वतः ॥१९॥
इन्दोर्गणाः[22] खखवियद्रसवृन्दनिघ्ना[23]
व्योम्नो भवेयुरिह[24] वृत्तसमानसंख्याः ।

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[1] °विक्षेपात् C. [2] खनवती A, B. [3] स···विष्णुक्रमाश्विनः C. [4] मन्दोच्चांशे C. [5] °तिरंशकाः A, B. [6] शीघ्राच्छोध्यग्रहाः A, B. [7] चाष्टत्रिकेषवः C. [8] विद्याविषमयोरपि A, B; विशेषसमयोरपि C. [9] पदयोःपश्चात् C. [10] °ऽष्टिदशैव A, B. [11] नवशरा C. [12] एकपञ्चाशकं A, B. [13] सूर्यचन्द्रमसोरतः A. [14] क्षिति···धा C. [15] कर्म missing from C. [16] कथ्यते C. [17] °समूहा विशोध्या B. [18] तच्च······गुणिता C. [19] द्विष्ठाशोध्यखाभ्रेषु खाब्धितः A, B; द्विष्ठाश्शोध्या लाभ्रेष खण्डिताः C. [20] वीषुम° A, B. [21] वाहुकोट्याः C. [22] इन्दोर्गणः A, B; इन्दोर्गुणाः C. [23] खखवियसद्रवृन्द निघ्नो A; खखवीयसवृन्द निघ्नो B. [24] °रथ A, B.

इष्टग्रहस्य भगणैर्गगनस्य वृत्तं
भङ्क्त्वाऽथ तस्य परिधिं लभते समन्तात्[1] ॥२०॥
निबन्धः कर्मणां प्रोक्तो योऽसावौदयिको विधिः ।
अर्धरात्रे त्वयं[2] सर्वो यो विशेषः स कथ्यते ॥२१॥
त्रिशती भूदिने[3] क्षेप्या ह्यवमेभ्यो[4] विशोध्यते ।
ज्ञगुर्वोर्भगणेभ्योऽपि[5] विंशतिश्च ततोऽब्धयः ॥२२॥
अष्टिश्शतगुणा[6] व्यासो योजनानां भुवो रवेः ।
खाष्टाब्ध्यङ्गानि शीतांशोः शून्यवस्वब्धयस्तथा[7] ॥२३॥
वस्विन्द्रियगुणच्छिद्रवस्वङ्गानि[8] विभावसोः ।
अङ्गाङ्गेष्वेकभूतानि चन्द्रकर्णः प्रकीर्तितः ॥२४॥
अष्टिरष्टौ[9] जिना रुद्रा[10] विंशतिर्द्व्यधिकाः[11] क्रमात् ।
दशघ्ना[12] गुरुशुक्रार्किभौमज्ञांशाः[13] स्वमन्दजाः ॥२५॥
मन्दवृत्तानि द्वात्रिंशन्मनवः[14] षष्टिरेव[15] च ।
खाद्रयो वसुदस्राः[16] स्युः शीघ्रवृत्तान्यथ क्रमात् ॥२६॥
द्व्यद्रयः[17] खाङ्गनेत्राणि खाब्धयोऽब्ध्यग्निदस्रकाः[18] ।
द्व्यग्नीन्दवो[19] रवेर्मन्दं[20] शुक्रवद् वृत्तमेव च ॥२७॥
एकत्रिंशत्क्षपाभर्तुरर्धरात्रे विधीयते[21] ।
पातभागाश्च[22] विज्ञेयाः पण्डितैः परिकल्पिताः ॥२८॥
मन्दशीघ्रोच्चयोः[23] क्षेप्यं चक्रार्धं बुधशुक्रयोः ।
राशित्रयं तु शेषाणां पात्यते[24] पातसिद्धये ॥२९॥
शुक्रार्किदेवपूज्यानां भागौ द्वावेव संयुतौ[25] ।
मन्दपाताच्च शीघ्रोच्चात्[26] सार्धांशस्तु कुजज्ञयोः[27] ॥३०॥

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[1] परिधिर्लभते समन्तात् A, B; परिधिं लभते समानात् C. [2] अर्धरात्रेश्चयं A, B. [3] त्रिशतिर्भूदिने A, B. [4] क्षेप्याऽप्यवमेभ्यो A; क्षेप्याप्यवमे द्यो B. [5] भृगुर्वोर्भ गणेभ्यो C. [6] अद्रिश्शतगुणो A, B. [7] शून्यावस्वब्धयः सदा C. [8] वस्विन्द्रीय° A; वस्वीन्द्रीय° B. [9] अर्वीरष्ट A,B. [10] द्रिघ्ना A,B; रुद्र C. [11] विंशतिद्व्यधिकाः B, C. [12] दशघ्नं C. [13] °भौमज्ञान्धि A, B; भौमज्यांशाः C. [14] मन्दवृत्तान्यथ किंशन्मनव A, B; मन्दवृत्तान्यपित्रिंशन्मनवः C. [15] …ष्टुरेव A, B. [16] वसुरुद्राः C. [17] द्व्यग्नयः A, B, C. [18] खाशुयोऽब्ध्यग्निदस्रकाः A; खाशुयोध्यग्निदस्रकाः B; खाब्धयो ह्यग्नि दस्रकाः C. [19] द्व्यद्रीन्दवो A, B. [20] रवेर्मन्द A, B, C. [21] ऽभिधीयते C. [22] वात° A; तेवाभा° B; पात missing from C. [23] मन्दोच्चयोः C. [24] वात्यते B. [25] कीर्तितौ A, B. [26] मन्दवाताच्च शीघ्रोच्वात् B; मन्दपातोच्च शीघ्रोच्चात् C. [27] भृगुज्ञयोः A, B .

विबुधानां च सर्वेषां शीघ्रपाताः प्रकीर्तिताः[१] ।
शोधयित्वा क्रमात् पातान् विक्षेपांशान्[२] प्रसाधयेत् ॥३१॥
योगविश्लेषनिष्पत्तिरेकानेकस्वदिग्वशात्[३] ।
विक्षेपः स स्फुटो ज्ञेयो ग्रहस्यैकस्य कीर्तितः ॥३२॥
अन्यस्याप्येवमेव स्याच्छेषाः प्रागुक्तकल्पनाः ।
एतत्सर्वं समासेन तन्त्रान्तरमुदाहृतम् ॥३३॥
शीघ्रमन्दोच्चचापार्धसंस्कृतात्स्वीयमन्दतः[४] ।
स्फुटमध्यग्रहाः[५] सर्वे विशेषः[६] परिकीर्तितः ॥३४॥

वेदाश्विरामगुणितान्ययुताहृतानि
चन्द्रस्य[७] शून्यरहितान्यथ मण्डलानि ।
स्वैः स्वैर्हृतानि भगणैः[८] क्रमशो ग्रहाणां
कक्ष्या भवन्ति खलु योजनमानदृष्टया[९] ॥३५॥

इति महाभास्करीये सप्तमोऽध्यायः ।

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[१] च कीर्तिताः C. [२] क्रमात्पाताद्विक्षेपांशात् A, B; क्रमात्पाताद्विक्षेपाशात् C. [३] °रनेक···स्वदिग्वशात् C. [४] शीघ्रोम° A, B. [५] स्फुटमध्याग्रहाः C. [६] विश्लेषः A, B. [७] ···चन्द्र C. [८] स्वैस्स्वैवतानि भगणौ A; स्वैस्स्वैवतानि भगणैः B. [९] योजनमानदृष्टा A, B, C.

## अष्टमोऽध्यायः

शशिवत्सरताडिते गणेऽह्नां
युगभूवासरभाजिते समादि[1] ।
अधिकाब्दगुणे[2] तथैव विद्या-
दुभयोरन्तरमर्कवर्षपूर्वम् ॥१॥

रविवर्षगणेन नास्ति कृत्यं[3]
परिशेषीकृतराशितोऽथ मासौ ।
धृतिसम्मितवासरान्[4] दिनेभ्यः
परिशोध्यैव ततो[5] भुजादि कार्यम् ॥२॥

रविसंहृतमर्ककाललब्धं
विपरीतं तु धनर्णमिन्द्वहेषु ।
शशिकेन्द्रजमप्यथाशु[6] चैवं
शशिवत्तच्छशिवासरेषु[7] कार्यम् ॥३॥

परिनिष्ठितनाडिका व्यतीताः[8]
शशिनो या दिवसस्य[9] षष्टिनिघ्नाः ।
स्फुटभोगविशेषसूर्यभागै-
र्भजितास्ताः स्फुटनाडिकास्तदाप्ताः ॥४॥

दिनमध्यच्छायार्कादुच्चविशुद्धाद् भुजाफलं[10] यत् स्यात्[11] ।
तत् क्षयधनविपरीतादविशेषविधे[12] रवेर्मध्यम् ॥५॥

ज्यासङ्कलितात्क्रमशः शोधितजीवामखिर्मखेश्शेषम् ।
मख्या हृतमन्त्याप्तं[13] पूर्वयुतं तद्भवति चापः[14] ॥६॥

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[1] तथा A, B. [2] अधिकाब्धगुणे A, B. [3] कृत्या A, B. [4] धृतिसंमितवासरात् C. [5] तदा A, B. [6] शशिकेन्द्रजमप्यथात्र C. [7] शशिवत्तचिवासरेषु B; ...शशिवासरेषु C. [8] ऽप्यतीता A, B. [9] दिवसविहीनतस्य B. [10] विशुद्धभुजाफले A; विशुद्धभुजाफलं B. [11] कृत्वा C. [12] तत्क्ष्यसनविपरीतादपिशेषविधे A; तत् क्ष्यतनविपरीतादपि शेषविधे B. [13] मध्याहृतमन्त्याप्तं A, B. [14] भवति तच्चापम् A, B.

साधांशकोऽक्षोऽष्टकलाविहीन[1]-
श्छाया दिनार्धे[2] समभूमिभागे ।
पञ्चाङ्गुला[3] द्वादशकस्य शङ्को[4]-
र्वदार्कमस्मिन्दिनमध्ययातम्[5] ॥७॥

अष्टौ लवाः[6] षोडशलिप्तिकोनाः
पलप्रमाणं[7] प्रवदन्ति यस्मिन् ।
छाया दिनार्धेऽर्धचतुर्थसंख्या
तत्राशु वाच्यः[8] सविता नभस्थः[9] ॥८॥

पञ्चाधिका विंशतिरक्षभागाः[10]
त्रिंशच्च यस्मिन् विहिताः पलस्य[11] ।
छाया तयोः शङ्कुसमा दिनार्धे
क्षिप्रं समाचक्ष्व[12] तयोः स्फुटार्कम्[13] ॥९॥

अक्षांशकाः[14] पञ्चदशैव यस्मिन्
छाया रवेः पञ्चमभागयुक्ता ।
सार्धाङ्गुला स्यात् सममण्डलोत्था[15]
वाच्यो[16] विवस्वान् खलु तत्र कीदृक् ॥१०॥

सप्तत्रिंशच्छाया सममण्डलजा[17] पलाङ्गुलास्त्रिंशत्[18] ।
वाच्यो जगत्प्रदीपः सममण्डलसंस्थितः सविता ॥११॥

छाया षोडश दृष्टा प्रागपरसमायता समे देशे ।
सार्धाः सप्त पलांशास्तत्र[19] विवस्वान् कियान् वाच्यः ॥१२॥

नीता रवेर्बलवता मरुता समस्ता
राश्यादयोऽत्र[20] गणिताः सह तत्पराभिः ।
शेषो मया परिगतः खलु तत्पराणां
सैकं[21] शतं कथय भानुमहर्गणं च ॥१३॥

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[1] साधांशकाक्षाष्ट° A; साधांशकोक्षाष्ट° B. [2] च्छायादिनार्धे A, B. [3] पञ्चाङ्गुल A, B; पञ्चाङ्गुलात् C. [4] शङ्कु C. [5] …स्मिन् दिनमध्ययातः A; आत्वात्स्मिन् दिनमध्ययातः B; …र्कमस्मिन् दिनमध्ययातम् C. [6] अष्टौ लवः A; अष्टो लवः B. [7] वलप्रमाणं A, B; फलप्रमाणं C. [8] तत्रापि वाप्यः C. [9] नभः स्थः A, C. [10] भाग C. [11] फलस्य A, B; लवस्य C. [12] चमाचक्ष्व B; त्वमाचक्ष्व C. [13] स्फुटार्कान् A, B; स्फुटार्कम् C. [14] अक्षांशका C. [15] °ऽक्षा C. [16] वाचो C. [17] समण्डलजा A, B. [18] पलाङ्गुलः° A, B. [19] सप्तफलांशास्तत्र C. [20] समन्ताद्राश्यादयोऽत्र C. [21] सैकां B.

राशिभागसहिताः शशिलिप्ता
बालहस्तपरिमृष्टविनष्टाः ।
पञ्चवर्गविकलाः[1] खलु दृष्टा-
स्ताभिरार्य[2] दिनराशिशशाङ्कौ ॥१४॥

राश्यंशका[3] हृता वात्या भागशेषस्त्रिसप्ततिः[4] ।
वाच्यो[5] भौमः कियांस्तत्र कीदृशो वाऽप्यहर्गणः ॥१५॥

राशित्रयं पञ्चदशांशयुक्तं
लिप्ता निशानाथसुतस्य पञ्च ।
एतत्समीक्ष्याथ गतान्यहानि[6]
यातानि तस्यैव च मण्डलानि ॥१६॥

मघवद्गुरुराशिभागलिप्ताः
शिशुना चपलेन नाशितास्ताः[7] ।
नव तत्र विलिप्तिकास्तु[8] दृष्टा
दिनराशिं गुरुमध्यमं च ताभिः[9] ॥१७॥

मण्डलादि भृगुजस्य सलिप्तं[10]
नष्टमत्र विकला दश दृष्टाः ।
सूर्यजस्य दश सप्तसमेता[11]
ब्रूहि तौ दिनगणावथ[12] शीघ्रम् ॥१८॥

पञ्च सप्त नव भौमशशाङ्कौ
राशिपूर्वगणितौ समवेतौ ।
उच्यतां दिनगणः शशिभौमौ
कीदृशौ च भटतन्त्रविदाशु[13] ॥१९॥

भौमशक्रगुरुमध्यविशेषः[14]
पञ्चराशिगणितः[15] परिपूर्णः ।

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[1] पञ्चवर्ग विकला B, C. [2] °रार्थ A, B; °रर्ध C. [3] रात्र्यंशका A, B. [4] वात्या भागशेषं त्रिसप्तभिः A; वात्या भागशेष त्रिसप्तभिः B; पात्या भाग शेषस्तु सप्ततिः C. [5] पात्यो C. [6] एतत्समीक्ष्याक्षगतान्यहानि A, B. [7] नाशितास्ताम् A, B. [8] लिप्ति-कास्तु B. [9] गुरुमध्यमाक्षताभिः A, B; गुरुमध्यमात्तथाद्भिः C. [10] सलिप्तौ A, B. [11] शास्तममेता C. [12] यदिगणवथ A; दिगणावथ B; ······दिगणावधि C. [13] भभतन्त्र-विदाशु A, B. [14] °शुक्र° A, B. [15] °गणितं A, B.

उच्यतां दिनगणः कलियातो
देवमन्त्रिरुधिरौ[1] च कियन्तौ ॥२०॥

सूर्याचन्द्रमसौ तुलाधरगतौ दृष्टौ मया तत्त्वतो
भागैर्द्वादशभिर्द्वयेन च युतौ सूर्यस्य वारोदये ।
लिप्ताभिः शशिशून्यसागरयुतौ जीवस्य वारे पुनः
शुक्रस्याथ शनैश्चरस्य दिवसे[2] तुल्यौ कियद्भिर्दिनैः[3] ॥२१॥

विलिप्ताभिरधिकोऽर्को विज्ञेयो भूधरेन्दुभिः ।
शोधयेच्च निशानाथाद्विलिप्ता धृतिसंमिताः[4] ॥२२॥

नाडीभिः कियतीभिरभ्युपगतादह्नां गणादागत-
स्तीक्ष्णांशोर्भगणादिकोऽत्र विलयं नीतोऽधुना[5] वात्यया ।
दृष्टः सप्ततिरेकरूपसहिता शेषः[6] कलानां मया
वक्तव्यो द्युगणो गतश्च सवितुः स्पष्टाश्च या[7] नाडिकाः॥२३॥

अर्काङ्गारकवासरैरपहृतः कश्चिद्दिनानां गणो
लब्धौ तत्र न वेद्मि नैव च[8] तयोः शेषौ मया लक्षितौ ।
यौ तौ मण्डलताडितावथ पुनर्भक्तौ दिनैः स्वैः[9] पृथक्
तत्राप्तं मरुताऽपनीतमधुना[10] चाग्रे तयोस्तिष्ठतः ॥२४॥[11]

अर्कस्याश्विनगाब्धिनागशिखिनः शेषः कुजस्योच्यते
भूताश्व्यङ्गनभोष्टशीतकिरणक्षोणीधरक्ष्माभृतः ।
एताभ्यां पृथगर्कभूमिसुतयोरह्नां गणौ तद्गतं
द्व्यग्रं चापि तयोर्विगणय्य गणका व्यावर्णयध्वं क्रमात् ॥२४*॥

भास्करे[12] मिथुनपर्यवसाने
शर्वरी त्रिगुणसप्तघटी स्यात् ।
अक्षचापगणितं[13] वद तस्मिन्
लम्बकेन सहितं विगणय्य ॥२५॥

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[1] देवमद्रिरुधिरौ A; देवमन्द्रिरुधिरौ B. [2] दिवसं C. [3] दिनर्द्धिर्दिनैः A; दिनद्धि-र्दिनैः B. [4] धृतिसंमताः A, B. [5] नाडीभिरभ्युपगतादह्नां गणा भागतः । तीक्ष्णांशुर्भग-णादिकेऽत्र निचिते नीतेऽधुना A, B. [6] °सहिताः शेषाः A,B. [7] ये A, B. [8] निवेश-नेव च A; नवे···नेव च B. [9] पुनर्भक्ते स्वदृष्टेः A; पुनर्भक्ते स्वैर्दृढै B. [10] मधुना-पनीतमधुना A, B. [11] The verses 23 and 24 do not occur in C. [12] अक्षप्रश्नास्करे C. [13] अक्षचापगुणता A, B.

भास्करेण परिचिन्त्य कृतोऽयं[1]
मन्दबुद्धिपरिबोधसमर्थः ।
सम्यगार्यभटकर्मनिबन्धः[2]
स्पष्टवाक्यकरणैः समवेतः ॥२६॥

स्पष्टार्थानेककरणैः[3] छेद्यके ग्रहणे[4] रवेः ।
यदिहास्ति तदन्यत्र यन्नेहास्ति न तत् क्वचित् ॥२७॥

इति महाभास्करीयेऽष्टमोऽध्यायः ।

इति महाभास्करीयं समाप्तम्

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[1] ततो या C. [2] कर्मनिबद्धः A, B. [3] स्पष्टानेककरणे C. [4] छेद्यकेन्द्रगणे A, B.

# महाभास्करीये प्रयुक्तपारिभाषिक-

# शब्दानाम् अनुक्रमणिका

महाभास्करीये प्रयुक्त-

## छन्दसाम् अनुक्रमणिका

# English Translation

OF THE

# MAHĀ-BHĀSKARĪYA

## CHAPTER I

## MEAN LONGITUDE OF A PLANET AND PLANETARY PULVERISER

Homage to God Śiva :

1. I bow to God Śambhu who bears on His forehead a digit of the Moon illumining all directions by its rays, to Him whose feet are adored by the gods and who is the source of all knowledge.

Homage to planets and stars :

2. Glorious are the rays of the Sun which make the lotus blossom forth, (and those) of the Moon whose beauty is like that of the damsel's face, (as also are) the long and clear rays of the stars including Jupiter; so also is the lustre of Mars, Mercury, Saturn, and Venus.

A benedictory stanza in appreciation of the *Āryabhaṭīya* and the pupils of Āryabhaṭa I :

3. May the accurate *Āśmaka-tantra* (*āśmakaṁ sphuṭa-tantraṁ*), which has been acquired by penance, live long in the world for its excellent qualities. May also the pupils of (Ārya)-bhaṭa, who are free from sins and have conquered the enemies of passions, live long.

The *āśmakaṁ sphuṭa-tantraṁ* ("the accurate *Āśmaka-tantra*"), according to the commentators Govinda Svāmī and Parameśvara, is the *Āryabhaṭīya* of Āryabhaṭa I (born 476 A.D.). Govinda Svāmī writes :

> "By this (stanza) the author exhibits the greatness of the *Āryabhaṭīya*, ..."

So also has said Parameśvara :

> "*tapobhiḥ* etc. is a benediction on the *Āryabhaṭa-tantra* and the pupils of Āryabhaṭa."

Exclusive references to Āryabhaṭa I and his work at several places in the present work and the name *Āryabhaṭa-karma-nibandha* ("a compen-

dium of the astronomical processes taught by Āryabhaṭa") given to this work by the author[1] indeed show that *āśmakaṁ sphuṭa-tantraṁ* is none else than the *Āryabhaṭīya.*

The word *āśmaka (aśmaka+aṇ)* literally means "pertaining to Aśmaka", and likewise *āśmakaṁ sphuṭa-tantraṁ* means "an accurate work on astronomy written, studied, or venerated in Aśmaka, or belonging to Aśmaka". This seems to suggest that Āryabhaṭa I, the author of that work, belonged to the Aśmaka country.[2] It is noteworthy in this connection that according to Nīlakaṇṭha (1500 A.D.) he was born in that country.[3]

Reference to the *Āryabhaṭīya* in the above stanza at the beginning of this work is meant, as stated in the *Prayoga-racanā* and by Govinda Svāmī to indicate the school to which the present work belongs.

## MEAN LONGITUDE OF A PLANET

A rule for calculating the *ahargaṇa* :

4-6. Add 3179 to the number of elapsed years of Śaka kings; then multiply (that sum) by 12; and then add the number of months elapsed (since the beginning of Caitra). Put down the result at two places. At one place multiply (that) by the number of intercalary months in a *yuga* and divide by the number of solar months in a *yuga*; and add the resulting intercalary months (omitting the fraction of a month) to the result put at the other place. Multiply tha tsum by 30 and then add the number of lunar days (*tithis*) elapsed (since the beginning of the current month). Set down the result (i.e., the sum obtained) at two places. At one place multiply that by the number of omitted lunar days (in a *yuga*) and divide by the number of lunar days (in a *yuga*), and subtract the resulting omitted lunar days (neglecting the fraction of a day) from the result set down at the other place. The result (thus obtained) is the number of (mean) civil days elapsed since the beginning of Kaliyuga (at mean sunrise at Laṅkā on the given lunar day). These

[1] See vs. 26 of Chapter VIII.

[2] For the Aśmaka country, see Part I, Chapter 2.

[3] See Nīlakaṇṭha's comm. on *Ā*, ii. 1.

days are said to have commenced with Friday and at sunrise (at Laṅkā).[1]

The above rule tells us how to determine the number of mean civil days elapsed at mean sunrise at Laṅkā on the given lunar day (*tithi*) since the beginning of Kaliyuga (when all the planets were in conjunction at the first point of the asterism Aśvinī). According to Āryabhaṭa I and Bhāskara I, the duration of Kaliyuga is 10,80,000 years and it began on Friday, February 18, B.C. 3102, at sunrise at Laṅkā[2] in the beginning of the month Caitra. The Śaka Era, which is usually used in Hindu astronomy for reckoning the years, commenced 3179 years after the beginning of Kaliyuga.

Caitra is the first month of the year. The months in Hindu astronomy are reckoned from one new moon to the next.

The *yuga* is a period of 43,20,000 years. At the beginning and end of a *yuga* the planets together with the Moon's apogee and ascending node are supposed to be in general conjunction. The number of intercalary months in a *yuga* denotes the excess of the number of lunar months in a *yuga* over the number of solar months in a *yuga*. The number of omitted lunar days in a *yuga* is equal to the number of lunar days in a *yuga* minus the number of civil days in a *yuga*. The number of intercalary months, omitted lunar days, etc., in a *yuga* are given in the seventh chapter[3].

In the rule stated above, the given true lunar month is treated as a mean lunar month and the given true lunar day is treated as a mean lunar day. The following is an explanation of the above rule :

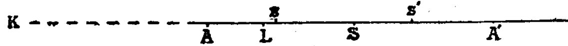



Fig. 1

Let K denote the beginning of Kaliyuga; AA′, the current mean lunar month; L, the beginning of the current mean lunar day; and s, the mean sunrise on that day. Also let S denote the beginning of the corresponding mean solar month[4]; and s′, the beginning of the mean solar day

[1] The same rule occurs also in *LBh*, i. 4-8 and *TS*, i. 23-26 (i). For other similar rules, see *SūSi*, i. 47-50; *BrSpSi*, i. 29-30, 34 (i); *ŚiDVṛ*, *I*, i. 15-17; *MSi*, i. 21-22; *SiŚe*, ii. 15-17; *SiŚi*, *I*, i (c), 1-3; *SiSā*, i. 44-47.

[2] Laṅkā is a hypothetical place where the Hindu prime meridian ("the meridian of Ujjain") intersects the equator.

[3] See verses 1-8.

[4] That is to say, if A is the beginning of the *t*th mean lunar month, then S is the beginning of the *t*th mean solar month.

corresponding to the current mean lunar day, so that the number of mean solar days between S and s′ is equal to the number of mean lunar days between A and L.

Adding 3179 to the number of elapsed years of the Śaka Era, we obtain the number of solar years elapsed since the beginning of Kaliyuga. Multiplying that sum by 12 and adding to the product the number of months elapsed since the beginning of Caitra, we get the number of mean solar months elapsed since the beginning of Kaliyuga. This number is equal to the number of mean solar months lying between K and S. (See Fig. 1.) Let us denote it by $M$. When we multiply $M$ by the number of intercalary months in a *yuga* and divide by the number of solar months in a *yuga*, we obtain the number of mean intercalary months corresponding to $M$ mean solar months. This number is, in general, made up of a whole number and a fraction. The fraction evidently denotes the fraction of a mean lunar month lying between A and S.[1] When the whole number of mean intercalary months is added to $M$, we get the number of mean lunar months lying between K and A.[2] When we multiply that by 30 and add to the product the number of lunar days (*tithis*) elapsed since the beginning of the current lunar month, we get the number of mean lunar days lying between K and L. Let us denote this number by $T$. When we multiply $T$ by the number of omitted lunar days in a *yuga* and divide by the number of lunar days in a *yuga*, we get the number of mean omitted lunar days corresponding to $T$ mean lunar days. This also, in general, consists of a whole number and a fraction. The fraction evidently denotes the part of a mean civil day lying between L and s.[3] When the whole number of mean omitted lunar days is subtracted from $T$, we get the number of mean civil days lying between K and s.[4] This is, in general, the number of mean civil days elapsed at mean sunrise at Laṅkā on the given lunar day since the beginning of Kaliyuga. This. number is known as "*ahargaṇa*" (literally meaning "a collection of days"). In the above passage, Bhāskara I has called it by the synonym *ahnāṁ nicayaḥ*.

The mean lunar day (*madhyama-tithi*) may, however, differ from a true lunar day (*spaṣṭa-tithi*) by *one*, so that the *ahargaṇa* obtained by the

[1] See *SiŚi, II*, iv. 16.

[2] If we add the whole number of mean intercalary months as also the fraction, we shall get the mean lunar days lying between K and *S*.

[3] See *SiŚi, II*, iv. 18 (i).

[4] If we subtract the whole number of mean omitted lunar days as also the fraction, we shall get the mean civil days lying between K and L.

above process may sometimes be in excess or defect by *one*. To test whether the *ahargaṇa* (obtained by the above process) is correct, it is divided by seven and the remainder counted with Friday. If this leads to the day of calculation, the *ahargaṇa* is correct; if that leads to the preceding day, the *ahargaṇa* is in defect; and if that leads to the succeeding day, the *ahargaṇa* is in excess. When the *ahargaṇa* is found to be in defect, it is increased by *one*; when it is found to be in excess, it is diminished by *one*.

Similarly, when a true intercalary month has recently occurred prior to the given lunar month or is about to occur thereafter, the true lunar month may differ from the mean lunar month by *one*. When a true intercalary month has occurred prior to the given month and the intercalary fraction amounts to one month approximately, then the whole number of mean intercalary months obtained in the above process is increased by *one*.[1] When no intercalary month has occurred prior to the given month but the intercalary fraction is small enough, the whole number of mean intercalary months obtained in the above process in diminished by *one*.[2]

The word *tithi* in verse 4 stands for 30. It is generally used to denote the number 15.

An alternative rule:

7. Or, multiply the number of (solar) months elapsed (since the beginning of Kaliyuga) by the number of lunar months (in a *yuga*) and divide by the number of solar months (in a *yuga*). Reduce the quotient to days (and add the number of lunar days elapsed since the beginning of the current lunar month); then multiply by the number of civil days (in a *yuga*) and divide by the number of lunar days (in a *yuga*); the quotient denotes the *ahargaṇa*.[3]

The number of solar months elapsed since the beginning of Kaliyuga is equal to the number of mean solar months lying between K and S.

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[1] "If the current lunar month is preceded by an intercalary month, then that intercalary month should also be treated as a lunar month." (Parameśvara).

[2] *Cf. SiŚi, I*, i (f). 3.

[3] The same rule occurs also in *BrSpSi*, xiii. 18 and *SiŚe*, ii. 3.

(See Fig. 1.) Let us denote this number by *M*, as before. When we multiply *M* by the number of lunar months in a *yuga*, and divide by the number of solar months in a *yuga* we obtain the number of mean lunar months corresponding to *M* mean solar days. This number is in general, made up of a whole number and a fraction. The whole, number, which is the quotient of the division, denotes the number of mean lunar months lying between K and A. Multiplying this by 30 and adding to it the number of lunar days elapsed since the beginning of the current month, we get the number of mean lunar days lying between K and L. Let us denote this number by *T* as before. When we multiply *T* by the number of civil days in a *yuga* and divide by the number of lunar days in a *yuga*, we get the number of mean civil days corresponding to *T* mean lunar days. If this number be a whole number, then it denotes the number of mean civil days lying between K and s and is therefore the *ahargaṇa*. (This case will occur when L and s coincide). If that number is made up of a whole number and a fraction, then the whole number as increased by one will be the *ahargaṇa*. This addition of one is not mentioned in the above stanza. It is stated later in verse 40.[1]

Statement of the proportion used in finding the mean longitude of a planet:

8. If from the civil days (corresponding to a *yuga*) we get the tabulated revolutions of a planet, how many of those (revolutions) will we get from the civil days elapsed since the beginning of Kaliyuga ? Thus (i.e., by applying this proportion) are obtained the revolutions (performed by the planet), and then successively the signs, degrees, minutes, seconds, and thirds (of the planet's mean longitude).[2]

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[1] "This *ahargaṇa* has sometimes to be increased by one as the author will say later." (Parameśvara). So also says Govinda Svāmī. See also *BrSpSi*, xiii. 18 and *SiŚe*, ii. 3.

[2] *Cf. SūSi*, i. 53; *BrSpSi*, i. 31; *LBh*, i. 15-17 (i); *ŚiDVṛ*, *I*, i. 21 (i); *MSi*, i. 25 (i); *SiŚe*, ii. 14; *SiŚi*, *I*, i (c). 4; *SiSā*, i. 53.

That is to say,

mean longitude of a planet in revolutions

$$= \frac{\text{(revolution-number of the planet)} \times \textit{(ahargaṇa)}}{\text{civil days in a } \textit{yuga}}.$$

A rule for deriving the mean longitude of a planet from that of the Sun:

9. Reduce the Sun's mean longitude (given in terms of signs, degrees, and minutes) together with the years elapsed (treated as revolutions) to minutes of arc. Multiply them by the planet's own revolution-number stated in the *Gītikā*[1] and divide (the product) by the number of (solar) years in a *yuga*. The result, say (the learned), is the planet's mean longitude in terms of minutes.

That is to say,

mean longitude of a planet in terms of minutes

$$= \frac{\text{(Sun's mean longitude in revolutions etc. reduced to minutes)} \times \text{(planet's revolution-number)}}{\text{Sun's revolution-number}}.$$

A rule for deriving the mean longitude of a planet from the mean longitude of the Moon or a planet or the *ucca* of a planet.

10. The (mean) longitude of the Moon, the planet, or the *ucca* (whichever is known) together with the revolutions performed should be reduced to minutes. The resulting minutes should then be multiplied by the revolution-number of the desired planet and (the product obtained should be) divided by the revolution-number of that (known) planet. The result is (the mean longitude of the desired planet) in terms of minutes.[2]

[1] This is the name of the first chapter of the *Āryabhaṭīya*.

[2] This rule occurs also in *BrSpSi*, xiii. 27; *ŚiDVṛ*, *I*, i. 30 (i); *SiŚe*, ii. 25-26; *SiŚi*, *I*, i (c). 14 (i).

That is to say
mean longitude of the desired planet in minutes

$$= \frac{\text{(mean longitude of the known planet in revolutions, etc., reduced to minutes)} \times \text{(revolution-number of the desired planet)}}{\text{revolution-number of the known planet}}.$$

This rule and the previous one are based on the following principle. If there are two planets $P$ and $Q$, then

revolution-number of $P$ : revolution-number of $Q$

: : (mean longitude of $P$ in revolutions etc.) : (mean longitude of $Q$ in revolutions etc.).

Alternative rules for deriving the mean longitude of the Moon from that of the Sun and *vice versa*:

11. Or, multiply the *ahargaṇa* by the number of intercalary months in a *yuga* and divide (the product) by the number of civil days (in a *yuga*) : the result is in terms of revolutions, etc. Add that to thirteen times the mean longitude of the Sun. (This is the process) to obtain the mean longitude of the Moon.[1]

12. Or, subtract the result obtained (in revolutions etc.) from the mean longitude of the Moon and take one-thirteenth of the remainder : this is stated to be the mean longitude of the Sun by the mathematicians whose intellect has been awakened by the grace of the teacher.

The following is the *rationale :*

We know that

intercalary months in a *yuga*
= lunar months in a *yuga* — solar months in a *yuga*.

But lunar months in a *yuga*
= Moon's revolution-number — Sun's revolution-number;

and solar months in a *yuga* = 12 (Sun's revolution number).

[1] This rule is found also in *BrSpSi*, xiii. 33; *ŚiDVṛ*, *I*, i. 24 (ii); *SiŚe*, ii. 19.

Therefore, we have

intercalary months in a *yuga*

= Moon's revolution-number — 13 (Sun's revolution-number),

giving

Moon's revolution-number

= intercalary months in a *yuga* + 13 (Sun's revolution-number).

Multiplying the two sides of this equation by the *ahargaṇa* and dividing by the number of civil days in a *yuga*, we get

mean longitude of the Moon

$$= \frac{(\text{intercalary months in a } yuga) \times (ahargaṇa)}{\text{civil days in a } yuga} \text{ revolutions}$$

$$+ 13 \text{ (Sun's mean longitude).} \quad \ldots \quad (1)$$

And rearranging this equation, we have

$$\text{mean longitude of the Sun} = (1/13) \left\{ \text{mean longitude of the Moon} - \frac{(\text{intercalary months in a } yuga) \times ahargaṇa}{\text{civil days in a } yuga} \text{ revolutions} \right\}. \quad \ldots \quad (2)$$

A rule for calculating the mean longitudes of the Sun and the Moon without making use of the *ahargaṇa* :

13-19. For one (desirous of) calculating the mean longitudes of the Moon and the Sun without the use of the *ahargaṇa*, the following method is stated :

Reduce the years (elapsed since the beginning of Kaliyuga) to months, and add to them the elapsed months (of the current year). Then multiply that (sum) by 30, and add the product to the number of (lunar) days elapsed since the beginning of the current month. Multiply that (sum) by the number of intercalary months (in a *yuga*) and divide by the number of solar months in a *yuga* reduced to days : the quotient denotes the number of intercalary months (elapsed). Delete (or rub out) the divisor

and divide the remainder (called *adhimāsaśeṣa*, i.e., the residue of the intercalary months) by the number of lunar months (in a *yuga*) : thus are obtained degrees, minutes, seconds, and thirds. Then multiply the (complete) intercalary months elapsed by 30 and to the product add the number of solar days (elapsed since the beginning of Kaliyuga) ; then multiply that (sum) by the number of omitted lunar days in a *yuga* and divide by the number of lunar days (in a *yuga*) : the remainder obtained is (the *avamaśeṣa*, i.e., the residue of the omitted lunar days) called *āhnika*. Then multiply the *avāmaśeṣa* by the number of intercalary months (in a *yuga*) and divide by the number of civil days (in a *yuga*). Add the resulting quotient to the *adhimāsaśeṣa* and then apply the process stated above (i.e., divide by the number of lunar months in a *yuga* : the result is in degrees, minutes, etc. This is the total *adhimāsaśeṣa*). Next multiply the *avamaśeṣa* called *āhnika* by 60 and divide by the number of civil days in a *yuga* : the result is in minutes, seconds, and thirds respectively. The number of months elapsed (since the beginning of Caitra) are to be taken as signs, and the number of lunar days elapsed (of the current month) as degrees. (The sum of these signs and degrees and the minutes, seconds, etc. corresponding to the *avamaśeṣa* is the *grahatanu*). From thirteen times and from one time that (*grahatanu*) severally subtract the degrees, minutes, etc. corresponding to the (total) *adhimāsaśeṣa* : the remainders (thus obtained) are stated by the wise astronomers to be the mean longitudes of the Moon and and Sun (respectively) conforming to the teachings of (Ārya)bhaṭa.[1]

The process described in the above rule is not in proper sequence. The direction given in verse 15 ought to have been after verse 17. Stated in proper sequence, the rule would be :

[1] This rule occurs also in *BrSpSi,* xiii. 20-22; *KK* (Sengupta), i. 11-12; and *SiŚe*, ii. 21-22. For similar rules, see *ŚiDVṛ, I,* i. 27, 25-26; and *SiŚi, I,* i (c). 6-7.

"Reduce the years (elapsed since the beginning of Kaliyuga) to months, and add to them the elapsed months (of the current year). Then multiply the sum by 30, and add the product to the number of (lunar) days elapsed since the beginning of the current month. Multiply that sum by the number of intercalary months (in a *yuga*) and divide by the number of solar months in a *yuga* reduced to days: the quotient denotes the number of intercalary months (elapsed). (The remainder is the *adhimāsaśeṣa).* Multiply the (complete) intercalary months (thus obtained) by 30 and to the product add the number of solar days (elapsed since the beginning of Kaliyuga)[1]; then multiply that (sum) by the number of omitted lunar days in a *yuga* and divide by the number of lunar days (in a *yuga*); the remainder obtained is (the *avamaśeṣa*) called *āhnika.* Then multiply the *avamaśeṣa* (called *āhnika*) by the number of intercalary months (in a *yuga*) and divide by the number of civil days (in a *yuga*). Add the resulting quotient to the *adhimāsaśeṣa* and divide the sum by the number of lunar months in a *yuga*: this gives degrees, etc. (This is the total *adhimāsaśeṣa.*) Next multiply (again) the *avamaśeṣa* called *āhnika* by 60 and divide by the number of civil days in a *yuga*: the result is in minutes, seconds, and thirds, etc. The number of months elapsed (since the beginning of Caitra) are to be taken as signs and the number of lunar days elapsed (of the current month) as degrees. (The sum of these signs and degrees, and the minutes, seconds, etc. corresponding to the *avamaśeṣa* is the *grahatanu).* From thirteen times and from one time that (*grahatanu*) severally subtract the degrees, minutes, etc. corresponding to the (total) *adhimāsaśeṣa*: the remainders (thus obtained) are stated by the wise astronomers to be the mean longitudes of the Moon and the Sun (respectively) conforming to the teachings of (Ārya)bhaṭa."

The following is the *rationale* of the above rule:

The fraction of the intercalary month (obtained in the rule)

$$= \frac{adhim\bar{a}sa\acute{s}e\d{s}a}{\text{solar days in a } yuga}, \quad \text{in mean lunar months.}$$

[1] By the number of solar days here is meant the number obtained above by 'reducing the years elapsed since the beginning of Kaliyuga to months, then adding to them the number of months elapsed since the beginning of the current year, then multiplying the sum by 30, and then adding to the product thus obtained the number of lunar days elapsed of the current month'.

$$= \frac{\textit{adhimāsaśeṣa}}{\text{lunar days in a } \textit{yuga}}, \text{ in mean solar months.} \qquad (1)$$

The fraction of the omitted lunar day (obtained in the rule)

$$= \frac{\textit{avamaśeṣa} \text{ or } \textit{āhnika}}{\text{lunar days in a } \textit{yuga}}, \text{ in mean civil days.}$$

$$= \frac{\textit{avamaśeṣa}}{\text{civil days in a } \textit{yuga}}, \text{ in mean lunar days.}$$

$$= \frac{\textit{avamaśeṣa} \times 60}{\text{civil days in a } \textit{yuga}}, \text{ in mean lunar } \textit{ghaṭīs}. \qquad (2)$$

The fraction of the intercalary month corresponding to the above fraction of the omitted lunar day

$$= \frac{(\text{intercalary months in a } \textit{yuga}) \times (\textit{avamaśeṣa})}{(\text{lunar days in a } \textit{yuga}) \times (\text{civil days in a } \textit{yuga})},$$

$$\text{in mean solar months.} \qquad (3)$$

Adding (1) and (3) and multiplying by 30, the total fraction of the intercalary month

$$= \left\{ \frac{\textit{adhimāsaśeṣa}}{\text{lunar months in a } \textit{yuga}} + \frac{(\text{intercalary months in a } \textit{yuga}) \times (\textit{avamaśeṣa})}{(\text{lunar months in a } \textit{yuga}) \times (\text{civil days in a } \textit{yuga})} \right\},$$

$$\text{in mean solar days.} \qquad (4)$$

Suppose that $m$ lunar months and $d$ lunar days have elapsed since the beginning of Caitra. Then, treating them as mean lunar months and mean lunar days, $m$ months and $d$ days denote the time elapsed since the beginning of mean Caitra up to the beginning of the current lunar day (treated as mean lunar day). As (2) is the interval, in mean lunar *ghaṭīs*, between the beginning of the current lunar day and the mean sunrise on that day, therefore

$$m \text{ months} + d \text{ days} + (2)$$

denotes the time in mean lunar months, days, and *ghaṭīs*[1] elapsed since the beginning of mean Caitra up to the mean sunrise on the current lunar day. Likewise

$m$ months + $d$ days + (2)—(4)

denotes the time in mean solar months, days, *ghaṭīs*, etc. elapsed since the beginning of the curent mean solar year up to the mean sunrise on the current lunar day.[2]

Let $M$, $D$, $G$, $V$, and $P$ denote respectively the mean solar months, mean solar days, mean solar *ghaṭīs*, mean solar *vighaṭīs*, and mean solar *pravighaṭīs* elapsed since the beginning of the current mean solar year up to the mean sunrise on the current lunar day. Then evidently

mean longitude of the Sun
= $M$ signs, $D$ degrees, $G$ minutes, $V$ seconds, and $P$ thirds.
= ($m$ signs and $d$ degrees) + [minutes, seconds, etc. corresponding to (2)]—[degrees, minutes, etc. corresponding to (4)];

and mean longitude of the Moon
= 13 [$m$ signs and $d$ degrees + (minutes, seconds, etc. corresponding to (2) ) ] — [degrees, minutes, etc. corresponding to (4) ],

because
(1/12) (mean longitude of the Moon — mean longitude of the Sun)
= $m$ signs + $d$ degrees + [minutes, seconds, etc. corresponding to (2) ].[3]

[1] 1 hour = $2\frac{1}{2}$ *ghaṭīs*,
1 *ghaṭī* = 60 *vighaṭīs*,
1 *vighaṭī* = 60 *pravighaṭīs*.

[2] Because (4) is equal to
{ fraction of a lunar month between the beginning of Caitra and the beginning of the current mean solar year } + { fraction of an intercalary month corresponding to the *tithis* elapsed up to the beginning of the current mean lunar day since the beginning of Caitra } + { fraction of an intercalary month corresponding to the *avamaśeṣa*, i.e, the lunar portion between the beginning of the current lunar date and the following sunrise }.

[3] This equality is based on the fact that the left hand side denotes the mean lunar date (*madhyama-tithi*). *Vide infra*, iv. 31.

It must be noted that, unless otherwise stated, the mean lunar day and the mean sunrise, etc., correspond to Laṅkā[1], and that 'the mean longitude of a planet' means 'the mean longitude for mean sunrise at Laṅkā'.

Śrīpati gives in addition to the above rule, the following two interesting rules also. It may be pointed out that Śrīpati uses a period of 4,32,00,00,000 years called a *kalpa* in place of a *yuga*.

Rule 1.

Moon's longitude = Sun's longitude + 12 $\left\{ \text{tithis elapsed up to the beginning of the current tithi} + \frac{\text{avamaśeṣa}}{\text{civil days in a kalpa}} \right\}$ degrees.

Sun's longitude = Moon's longitude — 12 $\left\{ \text{tithis elapsed up to the beginning of the current tithi} + \frac{\text{avamaśeṣa}}{\text{civil days in a kalpa}} \right\}$ degrees.

*Cf. SiŚe*, ii, 20.

Rule 2.

Moon's longitude = Sun's longitude + 12 $\left\{ (\text{tithis elapsed up to the beginning of the current tithi}) \text{ degrees} + (\text{Moon's daily motion in degrees} - \text{Sun's daily motion in degrees}) \times \frac{\text{avamaśeṣa}}{\text{lunar days in a kalpa}} \right\}$.

Sun's longitude = Moon's longitude — 12 $\left\{ (\text{tithis elapsed up to the beginning of the current tithi}) \text{ degrees} - \left\{ \frac{\text{avamaśeṣa}}{\text{lunar days in a kalpa}} \right\} \times (\text{Moon's daily motion in degrees} - \text{Sun's daily motion in degrees}) \right\}$.

*Cf. SiŚe*, ii. 24.

[1] *Vide supra*, p. 3 (footnote).

*Proof* :—

$$\frac{\text{Moon's longitude at sunrise} - \text{Sun's longitude at sunrise}}{12}$$

= *tithi* at sunrise

= *tithi* at the beginning of the current *tithi* + *tithi* corresponding to $\frac{avamaśeṣa}{\text{lunar days in a } kalpa}$

= *tithi* at the beginning of the current *tithi*

$$+ \frac{\text{Moon's daily motion in degrees} - \text{Sun's daily motion in degrees}}{12} \times \frac{avamaśeṣa}{\text{lunar days in a } kalpa},$$

because *tithi* corresponding to 1 civil day

$$= \frac{\text{Moon's daily motion in degrees} - \text{Sun's daily motion in degrees}}{12^\circ}.$$

Another rule for finding the mean longitude of a planet :

20. Divide the (*yojanas* of the) circumference of the sky by the number of civil days (in a *yuga*) : the result is the number of *yojanas* traversed (by a planet) per day. By those (*yojanas*) multiply the *ahargaṇa* and then divide (the product) by the length (in *yojanas*) of the own orbit of the planet. From that are obtained the revolutions, signs, etc. (of the mean longitude of the planet).

From stanza 8 above, we have

mean longitude of a planet

$$= \frac{(\text{revolution-number of the planet}) \times (ahargaṇa)}{\text{civil days in a } yuga}.$$

But from vii. 20

length of a planet's orbit

$$= \frac{\text{circumference of the sky}^1}{\text{revolution-number of the planet}}.$$

[1] For the length of the circumference of the sky, see vii. 20.

so that

revolution-number of a planet

$$= \frac{\text{circumference of the sky}}{\text{length of the planet's orbit}}.$$

Hence we have

mean longitude of a planet

$$= \frac{(\text{circumference of the sky}) \times \textit{ahargaṇa}}{(\text{civil days in a } \textit{yuga}) \times (\text{length of the planet's orbit})}.$$

Introduction to the topic discussed in the succeeding eighteen stanzas :

21. After a careful study of the ocean of the *Āśmakīya śāstras* (*śāstrārṇavam āśmakīyaṁ*) I reveal the planetary procedure, the secret there, (hitherto) unnoticed by the other followers of the *Āśmakīya* (*āśmakīyaiḥ*) by means of simplified rules (*laghu-tantra*).

*Āśmakīyaṁ* (literally meaning 'a book written by one born in or belonging to the Aśmaka country') refers to the *Āśmaka-tantra* (*i.e.*, *Āryabhaṭīya*) mentioned in stanza 3 above. *āśmakīyāḥ* means "the followers of the *Āśmakīya*", or, as the commentator Parameśvara says, "the pupils (or followers) of Āryabhaṭa I"[1].

The stanza under consideration shows that Bhāskara I, the author of the present work, was the earliest Āśmakīya ("follower of Āryabhaṭa I") to give the method of the *pratyabda-śuddhi* stated in the next eighteen stanzas. The method was, however, not invented by him. In his commentary on the *Āryabhaṭīya* he himself writes that it was already in use amongst the followers of the *Romaka-siddhānta*.[2] It occurs in the *Brāhma-sphuṭa-siddhānta* also.

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[1] "*āśmakīya āryabhaṭaśiṣyāḥ*" (Parameśvara)

[2] See comm. on *Ā*, iii. 10.

A rule for determining the number of mean lunar days lying between the beginning of mean Caitra and the beginning of the mean solar year :

22. Always having ascertained the number of years (elapsed since the beginning of Kaliyuga), multiply them by 11 and by 389/6000 (separately). Add the two results, and divide the sum (thus obtained) by 30. The quotient of division denotes (the mean intercalary) months, and the remainder (the mean intercalary) days.

The mean intercalary days obtained from this rule are equal to the number of mean lunar days lying between the beginning of mean Caitra and the beginning of the mean solar year.

The number of mean intercalary days in a mean solar year is equal to 11 + 389/6000. Hence the above rule.

A rule for finding the number of mean lunar days elapsed at the beginning of the mean solar year since the occurrence of a mean omitted lunar day :

23. Multiply (the number of years elapsed since the beginning of Kaliyuga) by 29 as divided by 36 (i.e., by 29/36). Again multiply the same (number of years) by 43 and divide by 72000. The sum of the two quotients gives the (residual mean omitted lunar) days. (Multiply the remainder of the first division by 2000, increase the product by the remainder of the second division, and then) divide (the sum) by 1125 : then are obtained (the mean lunar) days (which have elapsed at the beginning of the mean solar year since the occurrence of a mean omitted lunar day).

The number of mean omitted lunar days in a mean solar year is 5 + 29/36 + 43/72000; and the number of mean lunar days between two successive mean omitted lunar days is approximately 64. Hence the above rule.

A rule for finding the number of mean lunar days elapsed at the beginning of mean Caitra since the occurrence of a mean omitted lunar day :

24. From them (i.e., from the mean lunar days elapsed at the beginning of the mean solar year since the occurrence of a mean omitted lunar day) subtract the mean intercalary days (obtained in stanza 22 above): the remainder (obtained) is the time (in terms of mean lunar days) elapsed (at the commencement of mean Caitra) since the fall of a (mean) omitted lunar day. In case the subtraction is not possible, add 64 (to the minuend) and then from the sum perform the subtraction.

The subtraction is not possible when a mean omitted lunar day happens to fall between the beginning of mean Caitra and the beginning of the mean solar year. In such a case the omitted lunar days (obtained in stanza 23) should be diminished by *one*.

A rule for finding the lord of the year :

25-26(i). Divide the sum of the months[1] (which have elapsed at the beginning of the mean solar year since the beginning of Kaliyuga) and the (corresponding complete mean) intercalary months (obtained in stanza 22) by seven; and multiply the remainder by 30. Now we say what is to be subtracted from this: Divide the number of years elapsed since the beginning of Kaliyuga by seven and multiply the remainder (of the division) by five, add this product to the number of (residual mean) omitted lunar days (obtained in stanza 23) and divide the sum by seven: the remainder (of this division is the quantity to be subtracted). (Divide the difference of this quantity and the one obtained previously, by seven). The remainder increased by one counted with Friday gives the lord of the year (i.e., the planet presiding over the first day of Caitra). So has been stated by the learned.

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[1] These months are mean solar months and are obtained by multiplying the years elapsed since the beginning of Kaliyuga by twelve.

The number of mean civil days elapsed at the beginning of the mean solar year

= 12 × 30 × (solar years elapsed) + (11 + 389/6000) × (solar years elapsed) — (5+29/36+43/72000) × (solar years elapsed)

= 30 × (solar months elapsed + mean intercalary months obtained in stanza 22) + mean intercalary days obtained in stanza 22 — (5 × solar years elapsed + residual mean omitted lunar days obtained in stanza 23).

Therefore, the number of mean civil days elapsed on the first day of mean Caitra (or true Caitra)[1]

= 30 × (solar months elapsed + mean intercalany months obtained in stanza 22) — (5×solars years elapsed + residual mean omitted lunar days obtained in stanza 23).

When these civil days are increased by *one* and divided by seven, the remainder of the division counted with Friday gives the day on which Caitra begins. In the above rule the author has avoided big numbers by dividing by seven at every stage. His rule is therefore easy to apply in practice.

A rule for finding the the number of mean omitted lunar days occurring since the fall of the mean omitted lunar day just before the beginning of mean Caitra :

26(ii). Increase the number of (lunar) days (elapsed since the beginning of Caitra) by the number of (mean lunar) days elapsed (at the beginning of Caitra) since the fall of a mean omitted lunar day, and divide that (sum) by 64: the quotient gives the number of (mean) omitted lunar days (which have occurred since the mean omitted lunar day occurring before the beginning of Caitra) :

A rule for finding the number of mean lunar days lying between the beginning of mean Caitra and the beginning of the mean solar year (called "the subtractive") :

[1] The first day of true Caitra may sometimes differ from that of mean Caitra by one day.

27-28. Multiply the number of years (elapsed since the beginning of Kaliyuga) by 149 and then divide by 576: the quotient is in terms of days. Add these days to ten times the number of years (elapsed): thus are obtained the so called *ravija* days. To the *ravija* days add the (residual mean) omitted lunar days obtained above (in stanza 23). From the sum subtract the (complete mean) intercalary months (obtained in stanza 22) as multiplied by 30. Whatever is obtained as the remainder is "the subtractive" for the (current) year. When the subtrahend is greater, then the difference is prescribed as "the additive".

Let $Y$ denote the number of years elapsed since the beginning of Kaliyuga.

The number of mean civil days in one mean solar year

$= 365 + 149/576.$

Therefore, the number of mean civil days in $Y$ mean solar years

$= 365Y + (149/576)Y$

$= 365Y +$ residual mean civil days. (1)

The number of mean omitted lunar days in $Y$ mean solar years

$= (5 + 29/36 + 43/72000)Y$

$= 5Y +$ residual mean omitted lunar days. (2)

Adding (1) and (2), the number of mean lunar days in $Y$ mean solar years

$= 370Y +$ residual mean civil days

$+$ residual mean omitted lunar days. (3)

From (3) subtracting $360Y$ (i. e., the number of mean solar days in $Y$ years), the number of mean intercalary days in $Y$ solar years

$= 10Y +$ residual mean civil days

$+$ residual mean omitted lunar days. (4)

Subtracting the complete mean intercalary months (elapsed since the beginning of Kaliyuga as reduced to days) from(4),we get the residual mean intercalary days. These are equal to the mean lunar days lying between the

beginning of mean Caitra and the beginning of the mean solar year, and constitute the so called "subtractive."

The definition of the so called *grahatanu* for the Moon, Mars, Jupiter, and Saturn :

29. The number of years elapsed (since the commencement of Kaliyuga) multiplied by 360 is always called *grahatanu*. The (mean) longitudes (reduced to degrees) of the planets (Sun, Mercury, and Venus) together with the *grahatanu* are called *dhruvaka* by the learned.

The term *grahatanu* denotes the number of mean solar days elapsed at the beginning of the mean solar year since the beginning of Kaliyuga. This *grahatanu*, as remarks the commentator Parameśvara, is really a part of the *grahatanu*.

The *dhruvaka* (i.e., complete *grahatanu*) denotes the number of mean solar days elapsed on the given lunar day since the beginning of Kaliyuga. The above *dhruvaka*, or *grahatanu*, is defined for the Moon, Mars, Jupiter, and Saturn only; that for the Sun, Mercury, and Venus is defined in the next stanza.

The *grahatanu* for the Sun, Mercury, and Venus :

30. Diminish the (lunar) days elapsed since the beginning of Caitra by the corresponding complete omitted lunar days (obtained in the second half of stanza 26) and divide (the difference) by seven: the remainder (of the division) counted with the first day of Caitra is said to give the (current) day. From that, the "subtractive" for the year (obtained in stanzas 27-28) should also be subtracted. (But it must be remembered that) the minuend of this subtraction is the difference of the previous subtraction and not the other (i.e., not the remainder of the division). (The remainder obtained by subtracting the "subtractive" is the *grahatanu* for the Sun, Mercury, and Venus. It denotes the number of mean civil days elapsed since the beginning of the mean solar year).

The number of mean civil days elapsed since the beginning of the mean solar year is generally known as *laghvahargaṇa* ("smaller *ahargaṇa*").

Rules for finding the *laghvahargaṇa* occur in the *Brāhma-sphuṭa-siddhānta*[1], the *Śiṣya-dhī-vṛddhida*[2], the *Siddhānta-śekhara*[3], and the *Siddhānta-śiromaṇi*[4], etc., but the process described in the above rule is slightly different from them.

A rule for finding of the mean longitudes of the Sun, Mercury, and Venus :

31. Divide the *grahadeha* (for the Sun) by 70: the result is in days, etc. Then multiply one-fifth of the *grahadeha* by 2: the result is in *vighaṭikās*. These (days and *vighaṭikās*) subtracted from the *grahadeha* are stated to be (the degrees, minutes, etc. of) the mean longitudes of the Sun, Mercury, and Venus.[5]

The *grahadeha* is the same as *grahatanu* defined above. The following is the *rationale* of the above rule.

*Rationale 1.*

The *grahadeha* is in terms of mean civil days. This has to be converted into mean solar days.

The difference between civil and solar days in a *yuga*

$= 1577917500 - 1555200000$

$= 22717500$ days.

Therefore, this difference per mean civil day

$= 22717500/1577917500$ of a day

$= 1/70$ of a day $-$ $2/5$ of a *vighaṭikā* approx.

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[1] i. 42-43.

[2] *I*, i. 37.

[3] ii. 40-41(i).

[4] *I*, i(e). 12-13.

[5] The same rule occurs also in *ŚiDVṛ*, *I*, i. 39 and in *GL*, i. 10(i). Similar rules occur in *BrSpSi*, i. 44; *MSi*, i. 26 ; *SiŚe*, ii. 42, 43; *SiŚi*, *I*, i(d). 15; *SiSā*, i. 105; *KPr*, i. 4; *KKau*, i. 16; *KKu*, i. 7; and *SK*, i. 6 (i).

Hence the number of mean solar days corresponding to the desired *grahadeha*

$$= (1 - 1/70) \times grahadeha \text{ days}$$

$$- (2/5) \times (grahadeha) \text{ } vighaṭikās.$$

Consequently, the mean longitude of the Sun, Mercury, or Venus

$$= (1 - 1/70) \times (grahadeha) \text{ degrees}$$

$$- (2/5) \times (grahadeha) \text{ seconds.}$$

*Rationale II.*

The mean daily motion of the Sun

$$= \frac{4320000}{1577917500} \text{ of a revolution}$$

$$= \frac{4320000 \times 12 \times 30}{1577917500} \text{ of a degree}$$

$$= (1 - 3029/210389) \text{ of a degree}$$

$$= (1 - 1/70) \text{ of a degree } - \frac{1641 \times 60 \times 60}{210389 \times 70} \text{ of a second}$$

$$= (1 - 1/70) \text{ of a degree } - 2/5 \text{ of a second approx.}$$

Hence the rule.

A rule for finding the mean longitude of the Moon :

32. Multiply the *grahatanu* for the Moon by 83 (lit. $9^2 + 2$) and divide by 225; the result is in terms of degrees, etc. From that subtract the seconds obtained by multiplying the *grahatanu* by 11 and dividing by 50. (Then add the remainder to thirteen times the mean longitude of the Sun as prescribed in stanza 35 below : the sum thus obtained is the mean longitude of the Moon). [1]

---

[1] Similar rules occur in *SiDVṛ, I,* i. 40-41; *MSi,* i. 43(i); *SiSā*, i. 106; *KPr,* i. 5; *GL,* i. 10 (ii); *KKu,* i. 8; *KKau,* i. 17; and *SK,* i. 6(ii).

*Rationale I.*

The *grahatanu* for the Moon denotes the number of mean solar days elapsed since the beginning of Kaliyuga or the mean longitude of the Sun in revolutions, etc., reduced to degrees.

Since

$$\frac{\text{mean longitude of the Moon in revolutions etc.}}{\text{mean longitude of the Sun in revolutions etc.}}$$

$$= \frac{\text{revolution-number of the Moon}}{\text{revolution-number of the Sun}}$$

$$= \frac{57753336}{4320000}$$

$$= 13 + 83/225 - 264/4320000$$
$$= 13 + 83/225 - 11/(50 \times 60 \times 60),$$

therefore

mean longitude of the Moon

$$= 13 \times (\text{mean longitude of the Sun})$$
$$+ \frac{83 \times G}{225} \text{ degrees} - \frac{11 \times G}{50} \text{ seconds},$$

where $G$ is the *grahatanu* for the Moon.

*Rationale II.*

The mean motion of the Moon per solar day

$$= \frac{57753336}{4320000} \text{ degrees}$$

$$= \left\{13 + \frac{83}{225}\right\} \text{ degrees} - \frac{11}{50} \text{ of a second}$$

Therefore, the mean motion of the Moon for $G$ solar days, i.e., the mean longitude of the Moon

$$= \left\{13G + \frac{83G}{225}\right\} \text{ degrees} - \frac{11G}{50} \text{ seconds}$$

$$= 13 \times \text{Sun's mean longitude}$$
$$+ \frac{83G}{225} \text{ degrees} - \frac{11G}{50} \text{ seconds.}$$

A rule for finding the mean longitude of the Moon's ascending node :

33. Divide (the *grahatanu*) by 270 : these are degrees. Multiply (the *grahatanu*) by 113 and divide by 600 : these are seconds. These together with one-twentieth part of the (mean) longitude of the Sun (in revolutions, etc.) constitute the (mean) longitude of the Moon's ascending node. [1]

The mean motion of the Moon's ascending node per solar day

$$= \frac{232226}{4320000} \text{ of a degree}$$

$$= (1/20+1/270) \text{ of a degree} + 113/600 \text{ of a second.}$$

Hence the rule.

A rule for finding the mean longitude of the Moon's apogee :

34. Multiply the *grahatanu* by seven and divide by nine : these are minutes. Then multiply the *grahatanu* by 11 and divide by 60 : these are seconds. Then divide the *grahatanu* by 20 : these are thirds to be subtracted. These together with one-tenth of the Sun's (mean) longitude (in revolutions, etc.) constitute the (mean) longitude of the Moon's apogee :

The mean motion of the Moon's apogee per solar day

$$= \frac{488219}{4320000} \text{ of a degree}$$

$$= 1/10 \text{ of a degree} + 7/9 \text{ of a minute} + 11/60 \text{ of a second} - 1/20 \text{ of a third.}$$

Hence the rule.

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[1] Similar rules occur in *BrSpSi,* xxv. 35, and *ŚiDVṛ, I,* i. 52 (ii).

A rule for finding the mean longitude of the *śīghrocca* of Venus, and also giving the additives for the *śīghrocca* of Mercury and the Moon :

35. Multiply the *grahatanu* by 37 and divide by 900 : these are the degrees, etc., (forming part) of the (mean) longitude of (the *śīghrocca* of) Venus. Then divide the *grahatanu* by 100 : these are seconds. Add to these one-third of the Sun's (mean) longitude (in revolutions, etc.). Then subtract the whole of that (sum) from two times the Sun's (mean) longitude. (The difference thus obtained is the mean longitude of the *śīghrocca* of Venus).[1]

To the (mean) longitudes of (the *śīghrocca* of) Mercury and the Moon add four times the Sun's (mean) longitude and thirteen times the Sun's (mean) longitude respectively.[2]

The mean motion of the *śīghrocca* of Venus per solar day

$$= \frac{7022388}{4320000} \text{ degrees}$$

$$= (2-1/3-37/900) \text{ degrees} - 1/100 \text{ of a second.}$$

Hence the rule.

A rule for finding the mean longitude of the *śīghrocca* of Mercury:

36. Divide the *grahatanu* by 200: the result is in terms of signs. Then divide the *grahatanu* by 8: these are minutes. Then divide the *grahatanu* by 60: these are seconds. Adding all these (and also four times the Sun's mean longitude as prescribed in stanza 35) is obtained the (mean) longitude of (the *śīghrocca* of) Mercury.[3]

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[1] Similar rules occur in *BrSpSi*, xxv. 36 and *ŚiDVṛ*, *I*, i. 57 (ii).

[2] See stanzas 32 and 36.

[3] Similar rules occur in *BrSpSi*, xxv. 34 and *ŚiDVṛ*, *I*, i. 50 (ii).

The mean motion of the *śighrocca* of Mercury per solar day

$$= \frac{17937020}{4320000} \text{ degrees}$$

$= 1/200$ of a sign$+4$ degrees$+1/8$ of a minute$+1/60$ of a second.

Hence the rule.

A rule for finding the mean longitude of Saturn:

37. Multiplying the *grahatanu* by 8 and dividing by 225 are obtained minutes; and dividing (the *grahatanu*) by 300 are obtained seconds. Adding these two together and increasing that (sum) by one-thirtieth of the Sun's (mean) longitude is obtained the (mean) longitude of Saturn.[1]

The mean motion of Saturn per solar day

$$= \frac{146564}{4320000} \text{ of a degree}$$

$= 1/30$ of a degree$+8/225$ of a minute$+1/300$ of a second.

Hence the rule.

A rule for finding the mean longitude of Mars:

38. Multiply the *grahatanu* by two and subtract one-twentieth of itself from that: these are minutes, etc. Then divide the *grahatanu* by 50: these are seconds. Add these (minutes and seconds) to half the Sun's (mean) longitude (in revolutions, etc.): the sum is the (mean) longitude of Mars.[2]

The mean motion of Mars per solar day

$$= \frac{2296824}{4320000} \text{ of a degree}$$

$= 1/2$ of a degree $+ (2 - 2/20)$ minutes $+ 1/50$ of a second.

Hence the rule.

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[1] Similar rules occur in *BrSpSi*, xxv. 35 and *ŚiDVṛ*, *I*, i. 52 (i).
[2] Similar rules occur in *BrSpSi*, xxv. 33 and *ŚiDVṛ*, *I*, i. 50 (i).

A rule for finding the mean longitude of Jupiter :

39. Multiply the *grahadeha* by 22 and divide by 375 : these are minutes, etc. Add them to one-twelfth of the Sun's (mean) longitude (in revolutions, etc.) : the result is the (mean) longitude of Jupiter.[1]

The mean motion of Jupiter per solar day

$$= \frac{364224}{4320000} \text{ of a degree}$$

$$= 1/12 \text{ of a degree} + 22/375 \text{ of a minute.}$$

Hence the rule.

Corrections to be applied to the mean longitudes of the Moon's apogee and ascending node, and to the *ahargaṇa* :

40. Add three signs to the mean longitude of the Moon's apogee. Subtract the (mean) longitude of the Moon's ascending node from 12 signs and then add 6 signs. Also (if necessary) add *one* to the *ahargaṇa* obtained by proportion (in stanza 7 above). So say the astronomers whose hearts are devoted to Āryabhaṭa's system of astronomy (*bhaṭaśāstra*).

At the beginning of Kaliyuga, according to Āryabhaṭa I's system of astronomy, the mean longitude of the Moon's apogee was 3 signs and that of the Moon's ascending node 6 signs. Hence the addition of 3 signs to the mean longitude of the Moon's apogee and of 6 signs to the mean longitude of the Moon's ascending node prescribed by the author. The longitude of the Moon's ascending node has to be subtracted from 12 signs, because the motion of the Moon's ascending node is retrograde.

The remaining chapter deals with the solution of pulverisers (*kuṭṭākāra*) having reference to problems in astronomy.

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[1] Similar rules occur in *BrSpSi*, xxx. 35 and *ŚiDVṛ*, *I*, i. 51 (i).

## PLANETARY PULVERISER

Preliminary operation to be performed on the divisor and dividend of a pulveriser :

41. The divisor (which is "the number of civil days in a *yuga*) and the dividend (which is "the revolution-number of the desired planet") become prime to each other on being divided by the (last non-zero) residue of the mutual division of the number of civil days in a *yuga* and the revolution-number of the desired planet. The operations of the pulveriser should be performed on them (i.e., on the abraded divisor and abraded dividend). So has been said.

An indeterminate equation of the first degree of the type

$$\frac{ax - c}{b} = y$$

(with $x$ and $y$ unknown) is known in Hindu mathematics by the name of "pulveriser (*kuṭṭākāra*)". In this equation, $a$ is called the "dividend", $b$ the "divisor", $c$ the "interpolator", $x$ the "multiplier", and $y$ the "quotient".

In the pulveriser contemplated in the above stanza,

$a$ = revolution-number of a planet,

$b$ = civil days in a *yuga*,

$c$ = residue of the revolutions of the planet,

$x$ = *ahargaṇa*,

and $y$ = complete revolutions performed by the planet.

The text says that as a preliminary operation to the solution of this pulveriser, $a$ and $b$, i.e., civil days in a *yuga* and revolution-number of the planet, should be made prime to each other by dividing them out by their greatest common factor. That is to say, in solving a pulveriser one should always make use of abraded divisor and abraded dividend.

The interpolator, i.e., the residue, should also be divided out by the same factor. This instruction is not given in the text, but it is implied that the residue should be computed for the abraded dividend and abraded divisor.

A rule for solving a pulveriser, when the dividend is smaller than the divisor :

42-44. Set down the dividend above and the divisor below that. Divide them mutually, and write down the quotients of division one below the other (in the form of a chain). (When an even number of quotients are obtained) think out by what number the (last) remainder be multiplied so that the product being diminished by the (given) residue be exactly divisible (by the divisor corresponding to that remainder). Put down the chosen number (called *mati*) below the chain and then the new quotient underneath it. Then by the chosen number multiply the number which stands just above it, and to the product add the quotient (written below the chosen number). (Replace the upper number by the resulting sum and cancel the number below). Proceed afterwards also in the same way (until only two numbers remain). Divide the upper number (called "the multiplier") by the divisor by the usual process and the lower one (called "the quotient") by the dividend: the remainders (thus obtained) will respectively be the *ahargaṇa* and the revolutions, etc., or what one wants to know.

We explain this rule by means of an example.[1]

Example. The residue of the revolutions of Saturn is 24, find the *ahargaṇa* and the revolutions performed by Saturn.[2]

The revolution-number of Saturn is 146564, and the number of civil days in a *yuga* is 1577917500. In the present problem these are respectively the dividend and the divisor. Their H.C.F. is 4, so that dividing them out by 4 we get 36641 and 394479375 as the abraded dividend and the abraded divisor respectively. We have, therefore, to solve the pulveriser

$$\frac{36641x-24}{394479375}=y,$$

where $x$ denotes the *ahargaṇa* and $y$ the revolutions made by Saturn.[3]

[1] For other details, the reader is referred to B. Datta and A. N. Singh, *History of Hindu Mathematics*, Part II, P. 87 ff.

[2] Based on Bhāskara I's problem given in *LBh*, viii. 17.

[3] We have not divided the given residue 24 by 4, because it is already computed for the abraded dividend and abraded divisor.

Mutually dividing 36641 and 394479375, we have

```
36641) 394479375 (10766
       394477006
       ---------
           2369) 36641 (15
                 35535
                 -----
                  1106) 2369 (2
                        2212
                        ----
                         157) 1106 (7
                              1099
                              ----
                                 7) 157 (22
                                    154
                                    ---
                                     3) 7 (2
                                        6
                                        -
                                        1×27—24=3(1
                                                3
                                                -
                                                0
```

We have chosen here the number 27 as the optional number (*mati*).[1]

Writing down the quotients one below the other as prescribed in the rule, we get the chain

```
        10766
           15
            2
            7
           22
            2
(mati)     27
            1
```

[1] The *mati* may be chosen at any stage after an even number of quotients are obtained.

Reducing the chain, we successively get

| | | | | | | |
|---|---|---|---|---|---|---|
| 10766 | 10766 | 10766 | 10766 | 10766 | 3108044439 | (multiplier) |
| 15 | 15 | 15 | 15 | 288689 | 288689 | (quotient) |
| 2 | 2 | 2 | 18665 | 18665 | | |
| 7 | 7 | 8714 | 8714 | | | |
| 22 | 1237 | 1237 | | | | |
| 55 | 55 | | | | | |
| 27 | | | | | | |

Dividing 3108044439 by 394479375, and 288689 by 36641, we obtain 346688814 and 32202 respectively as remainders.[1] These are the minimum values of $x$ and $y$ satisfying the above equation.

Therefore, the required *ahargaṇa* = 346688814, and the revolutions performed by Saturn = 32202.

*General solution.* The general solution of the above equation (*vide* stanza 50) is

$$x = 394479375\alpha + 346688814,$$

$$y = 36641\alpha + 32202,$$

where $\alpha = 0, 1, 2, 3, \ldots\ldots\ldots\ldots$

An alternative rule :

45-46(i). Alternatively, the pulveriser is solved by subtracting *one* (i.e., by assuming the residue to be unity). The upper and lower quantities (in the reduced chain) are the (corresponding) multiplier and quotient (respectively). By the multiplier and quotient (thus obtained) multiply the given residue, and then divide the respective products by the abraded divisor and dividend. The remainders obtained are here (in astronomy) the *ahargaṇa* and the revolutions (performed respectively).

---

[1] This division is performed only when the multiplier and quotient are greater than the divisor and dividend respectively.

The pulveriser

$$\frac{ax - c}{b} = y \qquad (1)$$

may be written as

$$\frac{aX - 1}{b} = Y, \qquad (2)$$

where $x = cX$, and $y = cY$. If $X = \alpha$, $Y = \beta$ is a solution of (2), then $x = c\alpha$, $y = c\beta$ will be a solution of (1). Hence the above rule.[1]

A rule for finding the residue of revolutions from the longitude of a planet given in signs, etc.:

46(ii). (In case the longitude of a planet is given in terms of signs, etc.,) the signs, etc., are multiplied by the abraded number of civil days (in a *yuga*) and the product is divided by the number of signs, etc., (in a circle). The quotient is stated to be the residue (of revolutions).

When the longitude is given in terms of signs, it should be multiplied by the abraded number of civil days in a *yuga* and then the product should be divided by 12. The quotient thus obtained should be used as the residue of revolutions. When the longitude is given in terms of signs and degrees, it should be reduced to degrees, then the resulting degrees should be multiplied by the abraded number of civil days in a *yuga* and the product should be divided by 360. The quotient should be treated as the residue of revolutions. When the longitude is given in terms of signs, degrees, and minutes, it should be reduced to minutes, then the resulting minutes should be multiplied by the abraded number of civil days in a *yuga* and the product should be divided by 21600. The quotient should be used as the residue of revolutions.

Let $x$ be the *ahargaṇa*, $y$ the revolutions performed by a planet, and $s$ signs the given residue. Then

$$\frac{(\text{abraded revolution-number})\ x}{\text{abraded civil days}} - s \text{ signs} = y,$$

or

$$\frac{(\text{abraded rev.-number})\ x - \dfrac{(\text{abraded civil days})\ s}{12}}{\text{abraded civil days}} = y.$$

[1] For illustration see Example under stanza 46 (ii).

Hence the above rule.

Example. "The mean (position) of the Sun has been observed by me at sunrise to be in the sign Leo in the middle of the *navamāṁśa* Sagittarius. Calculate the *ahargaṇa* according to the *(Ārya)bhaṭa-śāstra*, and also the revolutions performed by the Sun since the beginning of Kaliyuga."[1]

The mean longitude of the Sun $= 4$ signs $28^\circ\ 20'$
$= 8900'$.

The abraded revolution-number of the Sun $= 576$,
and the abraded number of civil days in a *yuga* $= 210389$.

Hence, by the above rule, the residue of revolutions $= 86688$.

We have, therefore, to solve the equation

$$\frac{576\,x - 86688}{210389} = y,$$

where $x$ is the *ahargaṇa* and $y$ the number of revolutions performed by the Sun.

Solving this equation with unit residue, we get

$$x = 94602.$$
$$y = 259.$$

Deducing the solution for the given residue[2], we get

$$x = 105345,$$
$$y = 288,$$

which is the minimum solution of the problem. The general solution is

$$x = 210389\alpha + 105345,$$
$$y = 576\alpha + 288,$$

where $\alpha = 0, 1, 2, 3, \ldots$

A rule for solving a pulveriser when the dividend is greater than the divisor:

47. When the dividend is greater than the divisor, then, having subtracted the greatest multiple of the divisor (from

[1] Bhāskara I's example occurring in his comm. on *Ā*, ii, 32-33.

[2] See the rule given in stanzas 45-46(i).

the dividend), apply the same process (as prescribed in stanzas 42-44 or 45-46 (i) ). Multiply the multiplier (thus obtained) by that multiple and (to the product) add the quotient[1]: the result will be the quotient here (required).

Let the pulveriser be

$$\frac{ax - c}{b} = y, \qquad (1)$$

where $a > b$. Then if, $a = mb + A$, $A < b$, (1) may be written as

$$\frac{Ax - c}{b} = Y, \qquad (2)$$

where $y = Y + mx$.

If $x = \alpha$, $Y = \beta$, be a solution of (2), then $x = \alpha$, $y = m\alpha + \beta$ will be a solution of (1). Hence the above rule.

Example. "The signs, etc., up to the thirds of the Sun's (mean) longitude have all been carried away by the strong wind; the residue of thirds is known to me to be 101. Tell (me) the Sun's (mean) longitude and also the *ahargaṇa*."[2]

The abraded dividend for the Sun = 576 revolutions

$= 576 \times 12 \times 30 \times 60 \times 60 \times 60$ thirds
$= 44789760000$ thirds.

We have, therefore, to solve the equation

$$\frac{44789760000\, x - 101}{210389} = y, \qquad (3)$$

where $x$ is the *ahargaṇa* and $y$ the thirds described by the Sun since the beginning of Kaliyuga.

Since in this equation the dividend 44789760000 is greater than the divisor 210389, therefore, as directed in the above rule, we divide out the dividend by the divisor, and put the equation in the form

$$\frac{45790\, x - 101}{210389} = Y, \qquad (4)$$

[1] The literal translation is "the lower quantity (in the reduced chain)", which means "the quotient".

[2] *MBh*, viii. 13.

where $Y$ is related to $y$ by the relation $y = 212890\,x + Y$.[1]

Solving this equation, we get

$$x = 106141,$$
$$Y = 23101.$$

Hence the solution of the equation (3) is

$$x = 106141,$$
$$y = 212890\,x + Y$$
$$= 22596380591.$$

The required *ahargaṇa* is therefore 106141; and the mean longitude of the Sun is 22596380591 thirds, i.e., 3 signs, 32 degrees, 52 minutes, 23 seconds, and 11 thirds.

*Alternative method.* When $a > b$, the pulveriser

$$\frac{ax - c}{b} = y$$

may be written as

$$\frac{by + c}{a} = x,$$

which can be solved ordinarily by applying the rule stated in stanza 51 below.

A rule for solving the so called *vāra-kuṭṭākāra* (week-day pulveriser):

48. Divide the abraded number of civil days (in a *yuga*) by 7. Take the remainder as the dividend, and 7 as the divisor. Also take the excess 1, 2, etc., of the required day over the given day as the residue. Whatever number (i.e., multiplier) results on solving this pulveriser is the multiplier of the abraded number of civil days. The product of these added to the

[1] 212890 and 45790 are obtained as the quotient and the remainder when 44789760000 is divided by 210389.

*ahargaṇa* calculated (for the given day) gives the *ahargaṇa* for the required day[1].

This rule will become clear by the following solved example.

Example. "The mean longitude of the Sun (for sunrise) on a Wednesday is stated to be 8 signs, 25 degrees, 36 minutes, and 10 seconds. Say correctly after how much time (since the beginning of Kaliyuga) will the Sun again assume the same position (at sunrise) on a Thursday, Friday, and Wednesday."[2]

We first determine the *ahargaṇa* elapsed at sunrise on Wednesday when the Sun's mean longitude is 8 signs, 25 degrees, 36 minutes, and 10 seconds.

Since the Sun's mean longitude $= 8$ signs $25^\circ\ 36'\ 10''$
$= 956170''$,

therefore, by stanza 46(ii), the residue of revolutions $= 155222$.

Thus we have to solve the pulveriser

$$\frac{576\,x - 155222}{210389} = y,$$

where $x$ is the *ahargaṇa* and $y$ the revolutions performed by the Sun.

Solving this equation, we obtain

$$x = 1000,$$
$$y = 2.$$

Hence the *ahargaṇa* for the given Wednesday $= 1000$.

(i) Now we find out the *ahargaṇa* elapsed at sunrise on a Thursday when the Sun again occupies the same position.

Let the required *ahargaṇa* be $1000+A$. Then in $A$ days the Sun will describe complete revolutions. Also since Thursday is in advance of

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[1] The text is a little obscure at this place. Our translation is based on the interpretations given by the commentators. It also agrees with the details of the rule supplied by the author Bhāskara I himself in his commentary on $\bar{A}$, ii. 32-33.

[2] Bhāskara I's example occurring in his comm. on $\bar{A}$, ii. 32-33.

Wednesday by one day, the residue of the week-cycle is unity. In other words,

$$\frac{576A}{210389} \quad \text{and} \quad \frac{A-1}{7}$$

will be whole numbers. If we assume $A$ to be a multiple of 210389, we have simply to determine $A$ such that $A$—1 may be completely divisible by 7.

Let $A = 210389X$. Then we have to solve the pulveriser

$$\frac{210389X-1}{7} = Y, \tag{1}$$

or (*vide* stanza 47)

$$\frac{4X-1}{7} = Y', \tag{2}$$

where $Y = 30055\,X+Y'$. This is what the rule prescribes.

Evidently, a solution of (2) is $X = 2$, $Y' = 1$. The corresponding solution of (1) is $X = 2$, $Y = 30055\times2 + 1 = 60111$.

The required *ahargaṇa* is therefore $1000 + A$, i.e., $1000 + 210389X$ i.e., $1000 + 210389\times2$ or 421778.

(ii) To find the *ahargaṇa* for Friday.

In this case, the residue of the week-cycle is 2. Let the required *ahargaṇa* be $1000 + 210389X$. Then we have to solve the pulveriser

$$\frac{210389X-2}{7} = Y, \tag{3}$$

or (*vide* stanza 47)

$$\frac{4X-2}{7} = Y', \tag{4}$$

where $Y = 30055X+Y'$.

Evidently, a solution of (4) is $X = 4$, $Y' = 2$. The corresponding solution of (3) is $X = 4$, $Y = 30055X+2 = 120222$.

The required *ahargaṇa* is therefore 842556.

(iii) To find the *ahargaṇa* for Wednesday.

As before, let the *ahargaṇa* be $1000+210389X$. In this case, the residue of the week-cycle is 0 and we evidently have $X=7$, so that the required *ahargaṇa* is 1473723.

A rule for the solution of the so called *velā-kuṭṭākāra* (time-pulveriser) :

49. First make the abraded dividend and the (new)

divisor prime to each other. Then by what remains as the (new) divisor multiply the abraded divisor (and also the residue). Thereafter the process for the time-pulveriser is the same as described before (for the ordinary pulveriser).

This rule is applicable when the *ahargaṇa* is not a whole number but a whole number and a fraction[1]. That is to say, when the pulveriser is of the type

$$\frac{a(x \pm r/s) - c}{b} = y. \qquad (1)$$

Let $a = mA$, and $s = mB$, $m$ being the greatest common factor of $a$ and $s$. Then the equation (1) can be written as

$$\frac{AX - Bc}{Bb} = y, \qquad (2)$$

where $X = sx \pm r$.

The above rule tells us that whenever we have to solve an equation of the form (1), we must solve it by reducing it to the form (2). If $X = \alpha$, $y = \beta$ is a solution of equation (2), then $x = (\alpha \mp r)/s$, $y = \beta$ will be a solution of equation (1).

Example 1. "The (mean) longitude of the Sun for midnight is found to be 9 signs, 15 degrees, 32 minutes, and 40 seconds. Quickly say the *ahargaṇa* and the revolutions (performed by the Sun) according to the *Āśmakīya*." [2]

Since the mean longitude of the Sun = 9 signs 15° 32′ 40″, therefore, by stanza 46 (ii), the residue of revolutions = 166876.

We have, therefore, to solve the equation

$$\frac{576\,(x - 1/4) - 166876}{210389} = y, \qquad (3)$$

where $x - 1$ is the required *ahargaṇa* and $y$ the revolutions performed by the Sun.

As this equation is of the form (1), we reduce it to the form (2) as prescribed in the rule. Thus we get

$$\frac{144X - 166876}{210389} = y, \qquad (4)$$

where $X = 4x - 1$.

[1] The "(new) divisor" of the text is the denominator of this fraction.

[2] Bhāskara I's example, occurring in his comm. on *Ā*, ii. 32-33,

Solving equation (4), we get $X = 7003$, $y = 4$, giving $x = 1751$.

Hence the required *ahargaṇa* is 1750, and the number of revolutions performed by the Sun is 4.

Example 2. "The revolutions, etc., of the Sun's mean longitude, calculated from an *ahargaṇa* plus a few *nāḍīs* elapsed, have now been destroyed by the wind; 71 minutes are seen by me to remain intact. Say the *ahargaṇa*, the Sun's (mean) longitude, and the correct value of the *nāḍīs* (used in the calculation)." [1]

Here we have to solve the equation

$$\frac{576 \times 12 \times 30 \times 60(x+n/60) - 71}{210389} = y, \qquad (5)$$

where $x$ is the *ahargaṇa*, $y$ the minutes traversed by the Sun since the beginning of the Kaliyuga, and $n$ the *nāḍīs* elapsed.

As this equation is of the form (1), we reduce it to the form (2), and thus we get

$$\frac{207360X - 71}{210389} = y, \qquad (6)$$

where $X = 60x+n$.

Solving equation (6), we obtain

$$X = 43203,$$
$$y = 42581,$$

whence we have $x = 720$, and $n = 3$.

Hence the *ahargaṇa* is 720, the *nāḍīs* elapsed are 3, and the mean longitude of the Sun is 42581 minutes, i.e., 11 signs, 19 degrees, and 41 minutes.

A rule for getting the other solutions of a pulveriser with the help of the known minimum solution :

50. (To obtain the other solutions of the pulveriser) the intelligent (astronomer) should again and again add the divisor to the multiplier and the dividend to the quotient as in the process of *prastāra* ("representation of combinations").

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[1] Bhāskara I's example, occurring in his comm. on $\bar{A}$, iii. 32-33, and in *MBh*, viii. 23.

That is to say, if $x = \alpha$, $y = \beta$ is the minimum solution of the pulveriser

$$\frac{ax - c}{b} = y,$$

then the other solutions of the same pulveriser are

$$x = mb + \alpha,$$
$$y = ma + \beta,$$

where $m = 1, 2, 3, \ldots\ldots\ldots\ldots$

Procedure for problems in which the given quantity is the part of the revolution to be traversed by a planet:

51. When the part (of the revolution) to be traversed by some (planet) is the given quantity, then (also) the same process should be applied, treating the part to be traversed as the additive, or taking unity as the additive. All details of procedure are the same (as before).

The pulveriser contemplated above is of the type

$$\frac{ax + c}{b} = y. \qquad (1)$$

According to the above rule, this is to be solved in the same way as

$$\frac{ax - c}{b} = y, \qquad (2)$$

with the difference that wherever in solving (2) $c$ is subtracted, in solving (1) it should be added. Or, the solution of (1) may be derived as before from the solution of

$$\frac{ax + 1}{b} = y.[1] \qquad (3)$$

Example. "Given that 100 minutes of the eighth sign are to be traversed by the Sun, say quickly, after carefully considering, O intelligent one, if the *Gaṇita* of Āśmaka is known to you, all the years that have elapsed this day since the beginning of Kaliyuga. Also say the number of days that have elapsed since the beginning of Kaliyuga."[2]

[1] It is also possible to reduce the pulveriser (1) to the form (2). For, when the part of the revolution to be traversed by a planet is given, the part traversed may be easily derived therefrom.

[2] Bhāskara I's example, occurring in his comm. on $\bar{A}$, ii, 32-33.

Here, according to Bhāskara I's interpretation, the part of the revolution to be traversed by the Sun = 7 signs 100′. The corresponding residue of revolutions = 123707. This is positive.

We have, therefore, to solve the equation

$$\frac{576\,x + 123701}{210389} = y,$$

where $x$ is the required *ahargaṇa*, and $y$—1 the number of years elapsed.

Mutually dividing 576 and 210389 and taking 1 for the optional number (*mati*) after six quotients, we get the following chain

365
3
1
6
2
4
1 (*mati*)

which reduces to

61851
1310408037
3587617

Dividing 1310408037 by 210389 and 3587617 by 576, we obtain as remainders 105345 and 289 respectively. Therefore $x = 105345$, $y = 289$.

Hence the required *ahargaṇa* = 105345, and the number of years elapsed = 288.

Note. According to Govinda Svāmī's interpretation the part of the revolution to be traversed by the Sun = 4 signs $1^{\circ}$ 40′. The corresponding residue of the revolution = 71104.

The resulting pulveriser is

$$\frac{576x+71104}{210389} = y,$$

of which the solution is $x = 186889$, $y = 512$.

Therefore, the required *ahargaṇa* = 186889, and the number of years elapsed = 511.

Rules relating to the two cases: (i) when the sum or difference of the residues ( of revolutions ) of any two planets is given, and (ii) when the residues for two or more planets are given separately :

52. When the sum of the residues (of revolutions of two or more planets ) is given, proceed with the sum of their revolution-numbers (as the dividend); and when the difference between the residues ( for any two planets ) is given, proceed with the difference of their revolution-numbers ( as the dividend ). When the residues ( for two or more planets ) are given ( separately ), think out the method of solution by the help of the given residues and the true revolution-numbers of the given planets.

These rules will be clear from the following solved examples.

Example 1. "The sum of the (mean) longitudes of Mars and the Moon is calculated to be 5 signs, 7 degrees, 9 minutes, ( 9 seconds, and 6 thirds ). O you, well versed in the ( *Ārya* )*bhaṭa-tantra*, quickly say the *ahargaṇa* and also the (mean) longitudes of the Moon and Mars."[1]

The revolution-number of the Moon = 57753336.
The revolution-number of Mars = 2296824.
Their sum = 60050160.
The number of civil days in a *yuga* = 1577917500.

The H. C. F. of 60050160 and 1577917500 is 60. Therefore, the abraded sum of the revolution-numbers of the Moon and Mars

$= 60050160 \div 60 = 1000836,$

and the abraded number of civil days $= 1577917500 \div 60 = 26298625.$

The sum of the mean longitudes of the Moon and Mars

$= 5 \text{ signs } 7^{\circ}\, 9'\, 9''\, 6'''$

$= 33944946$ thirds.

Therefore, by stanza 46(ii), the residue of revolutions = 11480265. We have, therefore, to solve the equation

$$\frac{1000836\,x - 11480265}{26298625} = y,$$

[1] Bhāskara I's example ( *MBh*, viii. 19 ) with Govinda Svāmi's modification.

where $x$ denotes the required *ahargaṇa*.

The minimum solution of this equation is

$$x = 10157490,$$
$$y = 386459.$$

The required *ahargaṇa* is, therefore, 10157490. The mean longitudes of the Moon and Mars can be easily calculated from this *ahargaṇa*.

Example 2. "The difference between the mean longitudes of Mars and Jupiter is exactly 5 signs. Say what is the number of days elapsed since the beginning of Kaliyuga and what are the ( mean ) longitudes of Jupiter and Mars." [1]

| | | |
|---|---|---|
| The revolution-number of Mars | = | 2296824. |
| The revolution-number of Jupiter | = | 364224. |
| Their difference | = | 1932600. |
| Also the number of civil days | = | 1577917500. |

The H. C. F. of 1932600 and 1577917500 is 300. Therefore, the abraded difference of the revolution-numbers of Mars and Jupiter = 1932600 ÷ 300, i.e., 6442, and the abraded number of civil days = 1577917500 ÷ 300, i.e., 5259725.

The difference between the mean longitudes of Mars and Jupiter = 5 signs. Therefore, by stanza 46(ii), the residue of revolutions=2191552.

Hence we have to solve the equation

$$\frac{6442\,x - 2191552}{5259725} = y,$$

where $x$ denotes the required *ahargaṇa*.

The minimum solution of this equation is

$$x = 1133606,$$
$$y = 1388.$$

The required *ahargaṇa* is therefore 1133606. The corresponding mean longitudes of Mars and Jupiter may be easily obtained.

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[1] *Mbh*, viii. 20.

Example 3. "Some number of days is (severally) divided by the (abraded) civil days for the Sun and for Mars. The (resulting) quotients are unknown to me; the residues, too, are not seen by me. The quotients obtained by multiplying those residues by the respective (abraded) revolution-numbers and then dividing (the products) by the respective (abraded) civil days are also blown away by the wind. The remainders of the two (divisions) now exist. The remainder for the Sun is 38472, and that for Mars is 77180625. From these remainders severally calculate, O mathematician, the *ahargaṇas* for the Sun and Mars and also the *ahargaṇa* conforming to the two residues and state them in proper order."[1]

The abraded revolution-number and the abraded civil days for the Sun are 576 and 210389 respectively; the same for Mars are 191402 and 131493125 respectively.

Let $A$ be the number of days (i.e., the *ahargaṇa* conforming to the two residues). Then suppose that

$$\left.\begin{aligned} \frac{A}{210389} &= x + \frac{a}{210389} \\ \frac{A}{131493125} &= y + \frac{b}{131493125} \end{aligned}\right\} \qquad (1)$$

and

$$\left.\begin{aligned} \frac{576\,a}{210389} &= \beta + \frac{38472}{210389} \\ \frac{191402\,b}{131493125} &= \lambda + \frac{77180625}{131493125} \end{aligned}\right\}, \qquad (2)$$

where $A$, $x$, $y$, $a$, $b$, $\beta$, and $\lambda$ are all unknown quantities. The problem is to find $a$ and $b$ and therefrom $A$.

The equations (2) reduce to

$$\frac{576a - 38472}{210389} = \beta, \qquad (3)$$

$$\frac{191402\,b - 77180625}{131493125} = \lambda, \qquad (4)$$

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[1] Bhāskara I's example, occurring in his comm. on Ā, ii. 32-33. Also see *MBh*, viii. 24-24*.

Solving (3), we get $a = 8833$, $\beta = 24$; and solving (4), we get $b = 640000$, $\lambda = 931$.

Hence the *ahargaṇa* for the Sun is 8833, and that for Mars 931.

The equations (1) now reduce to

$$A = 210389\,x + 8833 = 131493125\,y + 640000,$$

whence we get the pulveriser

$$\frac{210389\,x - 631167}{131493125} = y,$$

i.e,
$$\frac{x - 3}{625} = y, \qquad (5)$$

The minimum solution of (5) is evidently

$$x = 628,$$
$$y = 1.$$

Hence $A = 132133125$.

The *ahargaṇa* conforming to the two residues $a$ ( = 8833 ) and $b$ ( = 640000 ) is therefore equal to 132133125.

CHAPTER II

# THE LONGITUDE-CORRECTION

Names of certain places lying on the Hindu prime meridian :

1-2. From Laṅka (towards the north, we have the following places on the prime meridian) : Kharanagara, Sitorugeha, Pāṇāṭa, Misitapurī, Taparṇī, the lofty mountain called Sitavara, the wealthy town called Vātsyagulma, the well known Vananagarī, Avantī, Sthāneśa, and then Meru, which is inhabited by happy people. For those who reside in these places, the correction for the longitude (of the local place) does not exist.

Laṅkā in Hindu astronomy denotes the place where the Hindu prime meridian passing through Ujjain[1] intersects the equator (i.e., the place in 0 latitude and 0 longitude). It is one of the four hypothetical cities on the equator, called Laṅkā, Romaka, Siddhapura, and Yamakoṭi. Laṅkā is described in the *Sūrya-siddhānta*[2] as a great city (*mahāpurī*) situated on an island (*dvīpa*) to the south of Bhārata-varṣa (India). The island of Ceylon which bears then ame Laṅkā, however, is not the astronomical Laṅkā, as the former is about six degrees to the north of the equator.

Kharanagara ("the town of Khara") is probably the place near Nasik where Khara, cousin of Rāvaṇa, lived. Sitorugeha has not been identified.

Pāṇāṭa seems to have been an important place, as it has been mentioned by other astronomers also, such as Lalla, Vaṭeśvara, and Śrīpati. Lalla has called it by the name Pārṇāṭā, and Śrīpati by the name Pānāṭa. We have not been able to identify this place also.

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[1] Situated in latitude 23° 11′ N. and longitude 75° 52′ east of Greenwich.

[2] xii. 37, 39.

Misitapurī and Taparṇī, too, remain unidentified. Śaṅkaranārāyaṇa in his commentary on the *Laghu-Bhāskarīya*[1] pronounces Misitapura as Nisitapura, so it is difficult to say which pronunciation is correct.

The Sitavara mountain ("the excellent white mountain") is the Śvetaṣaila of Lalla, the Sitādri of Śrīpati, and the Sitaparvata of Bhāskara II. According to Śrīpati, it is the seat of the six-faced god Svāmikārtikeya. It can therefore be identified with Krauñca-giri or Kumāra-parvata, situated at a distance of 3 *yojanas* from Śrīśaila.[2]

Vātsyagulma is the town of Vatsarāja Udayana, usually called Vatsapattana. It has been identified with Kauśāmbī (modern Kosam) situated on the river Jumna at a distance of about 38 miles from Allahabad.

Vananagarī[3] is probably Tumba-vana-nagara (modern Tumain) in Madhya Bhārata. Avantī is modern Ujjain. Sthāneśa is Sthāneśvara, a place in Kurukṣetra. Meru is the north pole.

From the above identification we find that the places ment oned in the text do not lie precisely on one meridian. The places mentioned by other astronomers also do not satisfy this requirement. It has not been possible to give any satisfactory explanation to this discrepancy. Probably the geographical knowledge of ancient Hindu writers was not sound in respect of places other than their own.

We give below the lists of places lying on the Hindu prime meridian according to other Hindu astronomers which will be useful for comparison and reference.

**(i) Lalla's list.**[4] Laṅkā, Kumārī, Kāñcī(varam), Pārṇāṭā, Kṛṣṇā (the river), Śvetaśaila ("the white mountain"), Vātsyagulma, Ujjayinī, Gargarāṭ, Āśraya (? Āśrama), Mālavanagara, Cāyuśiva (?), Rohītaka (Rohtak), Kurukṣetra (the battle field of the Bhārata War), Himavān (the Himalayas), and Meru.

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[1] i. 23.

[2] See *Kalyāṇa, Tīrthāṅka,* pp. 310 and 330.

[3] In case the correct reading is Varanagarī, it may be identified with Barnagar.

[4] Mentioned in Āmarāja's comm. on *KK*, i. 13.

(ii) **Vaṭeśvara's list.**[1] Laṅkā, Kumārī, Kāñcī, Mānāṭamaśvetapurī[2], Śveta Acala, Vātsyagulma, Avantī-pūḥ, Gargarāṭ, Āśrama-pattana, Mālava-nagara, Paṭṭaśiva, Rohitaka, Sthāṇviśvara (Sthāneśvara), Himavān, and Meru.

(iii) **Śrīpati's list.**[3] Laṅkā, Kumārī, Kāñcī-nagarī, Pāṇāṭa, Ṣaḍāsya Sitādri, Śrī Vatsagulma, Māhiṣmatī (modern Maheśvara situated on the north bank of river Narmada in Nimar district in Madhya Bhārata), Ujjayinī, Āśrama-nagara, Paṭṭaśiva, Śrī Gargarāṭ, Rohita (Rohtak), Sthāṇviśvara, Śitagiri (the Himalayas), and Sumeru.

(iv) **Bhāskara II's lists.**

1. Laṅkā-purī, Vatsagulma, Māhiṣmatī, Ujjayinī, Gargarāṭ, Kurukṣetra, Himācala, etc.[4]
2. Laṅkā, Devakanyā, Kāñcī, Sitaparvata, Paryalī, Vatsagulma, Ujjayinī-purī, Gargarāṭ, Kurukṣetra, and Meru.[5]

(v) **List of the Sūrya-siddhānta.**[6] Rākṣasālaya (i.e., Laṅkā), Devauka Śaila (i.e., Meru), Rohītaka (modern Rohtak), Avantī, and Sannihita Sara[7].

A rule for finding the distance of a place from the prime meridian :

3-4. Subtract the degrees of the latitude of one of the places (lit. towns) mentioned above from the degrees of the (local) latitude; then multiply (the degrees of the difference) by 3299 minus 8/25, and divide (the product) by the number of degrees in a circle (i.e., by 360). The resulting *yojanas* constitute the upright (*koṭi*). The oblique distance between the local

[1] *VSi*, chapter I, section ix, stanzas 1-2.

[2] A compound word giving the names of two places which probably correspond to Pāṇāṭa and Misitapurī mentioned in the text.

[3] *SiŚe*, ii. 95-97.

[4] Comm. on *ŚiDVṛ*, *I*, i. 55.

[5] *KKu*, i. 14.

[6] *SūSi*, i. 62.

[7] Sannihita Sara is in Kurukṣetra. See *Kalyāṇa, Tīrthāṅka*, p. 79.

place and the place (on the prime meridian) chosen above, which is known in the world by the utterance of the common people, is the hypotenuse. The square root of the difference between their squares (i.e., between the squares of the hypotenuse and the upright) is defined by some astronomers to be the distance (in *yojanas* of the local place from the prime meridian).[1]

In Fig. 2, let CD be a portion of the prime meridian and AB that of the local circle of latitude. Let L be the local place and X a place on the prime meridian. L and X being joined, we get the right-angled triangle XYL. The above rule tells us how to determine the distance YL of L from the prime meridian in linear units (i.e., in *yojanas*). The triangle XYL is supposed to be plane and sides XY, YL, and XL are taken as the upright (*koṭi*), the base (*bhuja*), and the hypotenuse (*karṇa*) respectively.

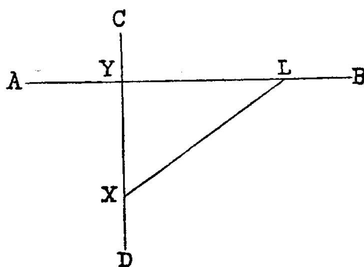


Fig. 2

Subtracting the degrees of the latitude of X from those of L (or Y), we get the length XY in terms of degrees. Now the circumference of the Earth is equal to 3299 minus 8/25 *yojanas* in linear units and to 360 degrees in circular units ; therefore, multiplying the degrees of XY by 3299 minus 8/25 and dividing the product by 360, we get the upright (*koṭi*) XY in terms of *yojanas*. The hypotenuse XL is assumed to be known in terms of *yojanas* by common usage. Hence the above rule.

*Earth's circumference.* In the above rule, as according to Bhāskara I also, the diameter of the Earth has been taken to be equal to 1050 *yojanas*[2] and $\pi$ equal to 3·1416. Therefore,

$$\begin{aligned}\text{the circumference of the Earth} &= 1050 \times 3{\cdot}1416 \ \textit{yojanas}\\ &= 3298{\cdot}68 \ \textit{yojanas}\\ &= (3299-8/25) \ \textit{yojanas}.\end{aligned}$$

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[1] This rule is found also in *BrSpSi,* i. 36 ; *LBh,* i. 25-26; *ŚiDVṛ, I,* 57-58 (i); *SiSā*, i. 143-144.

[2] *Vide infra,* chapter V, stanza 4.

In the *Laghu-Bhāskarīya,*[1] the author has neglected the fraction 8/25 and has given the whole number 3299 as the *yojanas* of the Earth's circumference. Lalla[2] has prescribed the more convenient number 3300.

Criticism of the above rule :

5. The distance (obtained above) has been stated to be incorrect by the disciples of (Ārya)bhaṭa, who are well versed in astronomy, on the ground that the method of knowing the hypotenuse is gross. (Those) wise people further say that on account of the sphericity of the earth (also), the method used for deriving the above rule commencing with "*akṣa*" is inaccurate.[3]

Śrīpati, too, has criticised the above rule for the same reasons. His commentator Makkibhaṭṭa sums up his criticism in the following words:

"The above rule is incorrect, because of the curvature of the Earth and because of uncertainty of the distances in *yojanas* depending on hearsay. No intelligent person has verified the popular (estimates of distances in) *yojanas* by actual measurement with the help of hand, staff, or rope. Therefore, in the face of plurality of popular estimates of distances, this rule is improper."[4]

It is noteworthy that the inaccurate rule criticised above occurs in the *Brāhma-sphuṭa-siddhānta*[5] of Brahmagupta and in the *Śiṣya-dhī-vṛddhida*[6] of Lalla.

Criticism of another rule :

6. Some (astronomers) say that the minutes of the difference between the true longitude of the Sun calculated from the midday shadow (of the gnomon at the local place)

[1] *LBh, i.* 24.
[2] *ŚiDVṛ*, *I*, i, 56.
[3] This criticism occurs also in *LBh*, i. 27 and *SiŚe*, i. 104.
[4] *SiŚe*, ii. 104(1), comm.
[5] i. 36.
[6] *I*, i. 57-58(i).

and the true longitude of the Sun calculated (from the *ahargaṇa*) for the middle of the day (without the application of the longitude-correction) give the longitude (correction for the Sun). This also is not so, because for people who live on the same parallel of latitude, the latitude (and therefore the shadow of the gnomon) is the same.[1]

This rule has also been criticised by Śrīpati, who says:

"Whatever is obtained here as the difference between the longitude of the Sun obtained from the midday shadow and that obtained by calculation (for midday, without the application of the longitude-correction) when multiplied by the (local) circumference[2] of the Earth and divided by the (Sun's daily) motion gives the *yojanas* of the longitude (i.e., the distance in *yojanas* of the local place from the prime meridian). This is gross on account of the small change in the Sun's declination."[3].

A rule for finding the longitude in time :

7. Those who have studied the astronomical *tantra* composed by (Ārya)bhaṭa and are well versed in Spherics state that the difference between the time of an eclipse calculated by the usual method from the longitudes of the Sun and the Moon (both) uncorrected for the longitude-correction and the time of the eclipse determined by observation is the more accurate value of the (longitude in) time.[4]

"Choice is made, of course, of a lunar eclipse, and not of a solar, for the purpose of the determination of longitude, because its phenomena, being unaffected by parallax, are seen everywhere at the same instant of absolute time ; and the moments of the total disappearance and first reappearance of the moon in a total eclipse are further selected, because

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[1] See also *LBh*, i. 28.

[2] The local circumference of the Earth is the circumference of the local circle of latitude.

[3] *SiŚe*, ii. 103.

[4] Similar rules occur also in *LBh*, i. 29; *SiŚe*, ii. 106(i); *TS*, i. 31(ii)-32(i).

the precise instant of their occurrence is observable with more accuracy than that of the first and last contact of the moon with the shadow".[1] Thus, says Nīlakaṇṭha, "whatever accrues as the difference between (the local times of) immersion (of a lunar eclipse) corresponding to the local and prime meridians is the time due to the longitude (of the local place). This may also be obtained from (the difference between the corresponding times for) the emersion of the lunar eclipse".[2]

The calculated time is the local time for the place lying at the intersection of the prime meridian and the local circle of latitude, while the observed time is the local time for the local place. The difference between the two is obviously the longitude in time for the local place.

Another rule :

8. On any day calculate the longitude of the Sun and the Moon for sunrise or sunset without applying the longitude-correction, and therefrom find the time (since sunrise or sunset), in *ghaṭīs*, of rising or setting of the Moon;[3] and having done this, note the corresponding time in *ghaṭīs* from the water-clock. The difference (between the two times), say the astronomers well versed in the *tantra* (composed by Āryabhaṭa ), is (the time of rising at the local place of a portion of the ecliptic equal to the motion-difference of the Sun and Moon corresponding to) the local longitude in time. (From this, the local longitude in time may be easily derived).

Let $\phi°$ N. be the latitude and $\lambda°$ E. the longitude of the local place. Also let $T_1$ *ghaṭīs* be the time of sunrise and $T_2$ *ghaṭīs* the time of moonrise at the place in latitude $\phi°$N. and longitude 0. Then $(T_2—T_1)$ *ghaṭīs* is the time of moonrise (as measured from sunrise) as calculated from the longitudes of the Sun and Moon uncorrected for the longitude-correction. For those longitudes correspond to true sunrise at the place in latitude $\phi°$N. and longitude 0.

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[1] Burgess, E., *Sūrya-siddhānta* (English translation), Calcutta (1935), p. 47.

[2] *Cf. TS*, i. 31(ii)-32(i).

[3] Rules for finding the time of moonrise are given in Chapter VI.

Thus the calculated time of moonrise $= T_2 - T_1$ *ghaṭīs*. (1)

At the local place, the time of sunrise on that day will be

$= (T_1 - \lambda/6)$ *ghaṭīs* ;

and the time of moonrise will be

$= (T_2 - \lambda/6)$ *ghaṭīs*—(the time of rising at the local place of a portion of the ecliptic equal to

$$\frac{\lambda \text{ (Moon's daily motion in minutes — Sun's daily motion in minutes)}}{360}$$

minutes of arc.)

Therefore at the time of moonrise the time indicated by the water-clock will be.

$(T_2' - T_1)$ *ghaṭīs*— (the time of rising at the local place of a portion of the ecliptic equal to

$$\frac{\lambda \text{ (Moon's daily motion in minutes—Sun's daily motion in minutes)}}{360}$$

minutes of arc). (2)

The difference between (1) and (2) gives the time of rising at the local place of a portion of the ecliptic equal to

$$\frac{\lambda \text{ (Moon's daily motion in minutes — Sun's daily motion in minutes)}}{360}$$

minutes of arc, which is evidently the time of rising at the local place of a portion of the ecliptic equal to the motion-difference of the Sun and Moon corresponding to the longitude of the local place. Hence the rule.

To obtain the local longitude in *ghaṭīs* we should multiply the above difference of (1) and (2) by 60 and divide the product (thus obtained) by the time in which an arc of the ecliptic equal to the difference between the daily motions of the Sun and Moon rises above the local horizon.[1]

Criteria for knowing whether the local place is to the east or to the west of the prime meridian:

9. When the rising of a planet is observed before the comupted time or the first contact of an eclipse is observed after the

[1] See Govinda Svāmī's commentary and the *Siddhānta-dīpikā*.

computed time,[1] the observer is to the east of the prime meridian. In the contrary case, he is to the west (of the prime meridian).[2]

The longitude correction and its application:

10(i). Multiply the (mean) daily motion of a planet the Sun, or the Moon's ascending node by the longitude in *ghaṭīs* and divide by 60. Apply the resulting correction to the (corresponding) mean longitude of the planet, the Sun, or the Moon's ascending node (calculated for mean sunrise at Laṅkā) positively or negatively according as the local place is to the west or east of the prime meridian. (Thus is obtained the mean longitude of the planet, the Sun, or the Moon's ascending node for mean sunrise at the *svanirakṣa* place[3]).[4]

Rule for finding the length of the local circle of latitude and the distance of the local place from the prime meridian:

10(ii). Multiply the number of (*yojanas in*) the Earth's circumference by the Rsine of the colatitude and divide by the radius; (the result is the number of *yojanas* in the local circle of latitude). Multiply that by the longitude in *ghaṭīs* and divide by 60; the result (thus obtained) is stated to be the (distance in) *yojanas* (of the local place from the prime meridian).[5]

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[1] The computed time corresponds to the place lying at the intersection of the local circle of latitude and the prime meridian.

[2] *Cf. LBh*, i. 29; *SūSi*, i. 63; *SiŚe*, ii. 105(i)-106(i).

[3] The *svanirakṣa* place is the place where the local meridian intersects the equator.

[4] This rule occurs also in *LBh*, i. 31 and *SiŚe*, ii. 106(ii).

[5] *Cf. SūSi*, i. 60(i), 64(ii)-65.

CHAPTER III

# DIRECTION, PLACE AND TIME. JUNCTION-STARS OF THE ZODIACAL ASTERISMS AND CONJUNCTION OF PLANETS WITH THEM

## (1) DIRECTION, PLACE AND TIME.

Setting up of the gnomon :

1. After having tested the level of the ground by means of water, draw a neat circle with a pair of compasses. (At the centre of that circle, set up a vertical gnomon). The gnomon should be large, cylindrical, massive, and tested for its perpendicularity by means of four threads with plumbs tied to them.

Bhāskara I in his commentary on the *Āryabhaṭīya*[1] tells us that there was difference of opinion amongst astronomers in his time regarding the shape and size of a gnomon (also called style). Some astronomers prescribed a gnomon with its one third in the bottom of the shape of a prism on a square base (*caturaśra*), one-third in the middle of the shape of a cow's tail *(gopucchākāra)*, and one-third at the top of the shape of a spear-head *(śūlākāra)*; and some others prescribed a square prismoidal (*samacaturaśra*) gnomon. The followers of Āryabhaṭa I, he informs us, prescribed the use of a broad (*pṛthu*), massive (*guru*), and large (*dīrgha*) cylindrical gnomon, made of excellent timber, and free from any hole, scar, or knot on its body. In the above stanza Bhāskara I prescribes this last kind of gnomon : the other two kinds he proves in the commentary to be defective and so he rejects them.

For getting the shadow-end easily and correctly, the cylindrical gnomon was surmounted by a fine cylindrical iron or wooden nail fixed vertically at the centre of the upper end. The nail was taken to be longer than the radius of the gnomon, so that its shadow was always seen on the ground. [2]

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[1] ii. 14.

[2] See Bhāskara I's commentary on *Ā*, ii. 13. Also see Parameśvara's commentary on *MBh*, iii. 1.

Certain writers, Bhāskara I tells us in the commentary, prescribed a gnomon of half a cubit (=12 *aṅgulas*) in length and having twelve divisions. But, according to Bhāskara I, (although it was the usual custom) there was no such hard and fast rule. The gnomon could be of any length and any number of divisions.[1] The gnomon should, however, be large enough, so that the rings of graduation on the gnomon may be clearly seen on the shadow. A broad and massive gnomon was preferred because it was unaffected by the wind.

As regards testing the level of the ground, Bhāskara I observes:

"When there is no wind, place a jar (full) of water upon a tripod on the ground which has been made plane by means of eye or thread, and bore a (fine) hole (at the bottom of the jar) so that the water may have continuous flow. Where the water falling on the ground spreads in a circle, there the ground is in perfect level; where the water accumulates after departing from the circle of water, there it is low; and where the water does not reach, there it is high."[2]

The same test has been prescribed by Govinda Svāmī[3] and Nīlakaṇṭha.[4]

After the ground was levelled, a prominently distinct circle was drawn on the ground as stated in the text. In the time of Śaṅkaranārāyaṇa (869 A. D.) it seems that all lines were drawn on the ground with sandal paste (*candanakṣodārdra*).[5] The above circle having been thus drawn and coated with sandal paste, another small concentric circle was drawn with the radius of the gnomon. The gnomon was then placed vertically with the periphery of its base in coincidence with that circle. The gnomon was thus set up exactly in the middle of the bigger circle. The verticality of the gnomon was tested by means of four plumb-lines hung on the four sides of the gnomon.

A rule for finding the directions :

2. With the two points where the shadow (of the gnomon) enters into and passes out of the circle, neatly draw a fish-figure (lit. fish). The thread-line which goes through the

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[1] See Bhāskara I's comm. on *Ā*, ii. 14.

[2] Bhāskara I's comm. on *Ā*, ii. 13.

[3] In his comm. on *MBh*, iii. 1.

[4] In his comm. on *Ā*, ii. 13.

[5,6] *Vide* Śaṅkaranārāyaṇa's comm. on *LBh*, iii. 1-2.

mouth and tail of the fish-figure indicates the north and south directions with respect to the gnomon.[1]

Let ENWS (See Fig. 3) be the circle drawn on the ground, and O its centre where the gnomon is set. Let $W_1$ be the point where the shadow enters into the circle ( in the forenoon ), and $E_1$ the point where the shadow passes out of the circle (in the afternoon). Join $E_1$ and $W_1$. The line $E_1W_1$ is directed east to west. With $E_1$ as centre and with $E_1W_1$ as radius[2] draw an arc of a circle, and with $W_1$ as centre and with the same radius draw another arc cutting the former at the points $N_1$ and $S_1$. Join $N_1$ and $S_1$. The line $N_1S_1$ is directed north to south. Let the line $N_1S_1$ meet the circle in the points N and S and the line through O drawn parallel to $E_1W_1$ in E and W. Then E, W, N, and S are respectively the east, west, north, and south directions relative to the gnomon, i.e., for an observer situated at O.

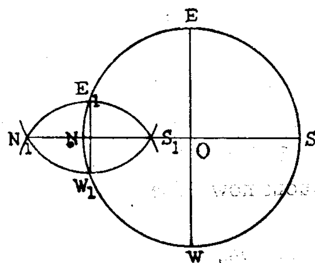



Fig. 3

The figure $N_1E_1S_1W_1N_1$ is called "fish or fish-figure"[3], and the points $N_1$ and $S_1$ are called the mouth and tail of the fish-figure.

As the Sun moves along the ecliptic, its declination changes. By the time the shadow moves from $OW_1$ to $OE_1$, the Sun traverses some distance of the ecliptic and so, theoretically speaking, its declination gets changed. It follows that EW is not the true position of the east-west line. Brahmagupta (628 A.D.) was probably the first Hindu astronomer who prescribed the determination of the east-west line with proper allowance for the change in the Sun's declination. The details of the method intended

[1] This rule is found also in *SūSi*, iii. 1-4; *BrSpSi*, iii. 1; *LBh*, iii. 1; *ŚiDVṛ, I*, iii.1; *MSi*, iv. 1-2; *SiŚe*, iv. 1-3; and *SiŚi, I*, iii. 8-9.

[2] In general, as Parameśvara says in his comm. on *LBh*, iii-1-3 this radius may be any length greater than (1/2) $E_1W_1$.

[3] Varāhamihira calls this figure "*yava* (barley or barley-figuresr. also." See *PSi*, iv. 19.

by him have been supplied by his commentator Pṛthūdaka Svāmi (860 A.D.)[1] The method of getting the correct east-west line is found to occur also in the *Siddhānta-śekhara*[2] of Śrīpati (c. 1039 A.D.) the *Śiddhānta-śiromaṇi*[3] of Bhāskara II (1150 A.D.) etc. For practical purposes, however, the method given in the text is good enough.

An alternative rule :

3. With the three points (at the ends of the three shadows of the gnomon) corresponding to (any three) different times (in the day), draw two fish-figures (each with two of the three points) in accordance with the usual method. From the point of intersection[4] of the lines passing through the mouth and tail (of the two fish-figures), determine the north and south directions.[5]

According to this rule, the north-south line is the one joining the foot of the gnomon with the point of intersection of the mouth-tail lines of the two fish-figures.

Varāhamihira states this rule as follows :

"Mark three times, from the centre, the end of the gnomon's shadow, and then describe two fish-figures. Thereupon describe a circle, taking for radius a string, that is fastened to the point in which the two strings issuing from the heads of the fish-figures intersect, and that is so long as to reach the three points marked. On the given day the shadow of the gnomon moves in that circle, without departing from it.

"The line joining the centre of that circle and the base of the gnomon is the south-north line ; and the interval in north direction (between that circle and the gnomon) is the midday shadow."[6]

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[1] See Sudhākara Dvivedī's comm. on *BrSpSi*, iii. 1.

[2] iv. 14-16.

[3] *I*, iii. 8.

[4] This point of intersection is the same as the centre of the circle passing through the three shadow-ends.

[5] This rule is found also in *PSi*, xiv. 14-16 ; *BrSpSi*, iii. 2 ; *ŚiDVṛ*, *I*, iii. 2 ; and *SiŚe*, iv. 4.

[6] See G. Thibaut and S. Dvivedi, *The Pañca-siddhāntikā*, Banaras (1889), xiv, 14-16, English translation, p. 79.

Brahmagupta is more precise. He says :

"The point where the lines passing through the two fish-figures, which are drawn by means of three shadow-ends (of the gnomon), intersect each other is, for places in the northern hemisphere, the south direction[1] (if the midday shadow falls to the north of the foot of the gnomon). If the midday shadow falls towards the south of the foot of the gnomon, it is the north direction".[2]

The above rule is evidently based on the assumption that the locus of the end of the shadow of the gnomon is a circle. In fact, for places whose latitudes are less than $90°-\epsilon$ (where $\epsilon$ is the obliquity of the ecliptic), this locus is a hyperbola, so the above assumption is not a correct one. The above rule will, however, give an approximately correct result if the three shadow-ends chosen are not far removed from the vertex of the hyperbola.

The method of drawing a circle through three given points by the aid of two fish-figures is called "*triśarkarā-vidhāna*" by Bhāskara I.[3]

A rule for getting the length of the hypotenuse of the shadow :

4. The square root of the sum of the squares of the gnomon and its shadow (is equal to the hypotenuse of the shadow : this), say the learned (astronomers), is always the semi-diameter of its own circle in the calculations with the shadow.[4]

By "the semi-diameter of its own circle" is meant "the semi-diameter of the circle of shadow".

The circle of shadow is, as Bhāskara I has said[5], useful in the application of proportion in connection with the problems involving the shadow of the gnomon. For example, in finding out the Rsine[6] of the Sun's zenith distance from the shadow of the gnomon, the proportion is :

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[1] The north direction being indicated by the end of the midday shadow of the gnomon.

[2] *BrSpSi*, iii. 2.

[3] See *LBh*, vi. 16.

[4] This rule is found also in *Ā*, ii. 14.

[5] In his commentary on *Ā*, ii. 14.

[6] Rsine stands for "radius × sine".

"When to the radius of the circle of shadow corresponds the shadow of the gnomon, what will correspond to the radius of the celestial sphere ? The result is the Rsine of the Sun's zenith distance".

Rules for finding the latitude and colatitude and the zenith distance and altitude of the Sun :

5. Multiply the radius by (the length of) the shadow and (at another place) by (the length of) the gnomon. Divide (the two results) separately by the square root (obtained above). When this calculation is performed for an equinoctial midday, the (two) results denote the Rsine of the latitude and the Rsine of the colatitude (respectively); elsewhere, they denote the great shadow (i.e., the Rsine of the Sun's zenith distance) and the great gnomon (i.e., the Rsine of the Sun's altitude) (respectively).[1]

That is

$$\text{Rsin } \phi = \frac{\text{equinoctial midday shadow} \times \text{radius}}{\text{hypotenuse of equinoctial midday shadow}},$$

$$\text{Rsin } C = \frac{\text{gnomon} \times \text{radius}}{\text{hypotenuse of equinoctial midday shadow}},$$

and

$$\text{Rsin } z = \frac{\text{shadow} \times \text{radius}}{\text{hypotenuse of shadow}},$$

$$\text{Rsin } a = \frac{\text{gnomon} \times \text{radius}}{\text{hypotenuse of shadow}},$$

where $\phi$ and $C$ denote the latitude and colatitude of the place, and $z$ and $a$ denote the zenith distance and altitude of the Sun.[2]

These results are easily proved by assuming that the rays coming from the Sun are parallel.

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[1] This rule is found also in *SūSi*, iii. 13-14; *BrSpSi*, iii. 10; *LBh*, iii. 2-3; *ŚiDVr*, *I*, iii. 4-5; *SiŚe*, iv. 7; and *SiŚi*, *I*, iii. 18.

[2] The equinoctial midday shadow is the shadow cast by the gnomon at midday at an equinox.

In fact, however, the rays coming from the Sun are not exactly parallel, so that the angle between the gnomon and the Sun's ray reaching the ground through the upper end of the gnomon is not exactly equal to the zenith distance of the Sun. Moreover, the shadow which is actually measured is the umbra (i.e., the shadow between the foot of the gnomon and the point where the ray coming from the uppermost point of the Sun's disc and passing through the upper end of the gnomon meets the ground) and not the theoretical shadow corresponding to the central ray of the Sun coming through the upper end of the gnomon. Later Hindu astronomers have, therefore, prescribed corrections to the results determined according to the rules in the above stanza.[1]

For practical purposes the rules stated above are good enough. The error is negligible.

Rules for determining the declination, day-radius, earthsine, and ascensional difference (for the Sun or a point on the ecliptic):

6-7. Multiply the Rsine of the given longitude by 1397 and always divide by the radius; the result is the Rsine of the declination for that time. Subtract the square of that (Rsine of the declination) from the square of the radius and then take the square root (of the difference); the result is called the day-radius.[3] Multiply the Rsine of the latitude by (the Rsine of) the given declination and divide by (the Rsine of) the colatitude: the result is the earthsine.[4] Multiply the earthsine by the radius and then divide (the product) by the day-radius; then reduce (the resulting Rsine) to arc. Whatever (arc) is thus obtained is termed "the ascensional difference" by the best amongst the good (astronomers).[5]

[1] These corrections occur in *KPr*, iv. 2; *KP*, viii. 3; and *TS*, iii. 10(ii)-11.

[2] This rule is found also in *S Si*, ii. 28; *BrSpSi*, ii. 55; *LBh*, ii. 16; *ŚiDVṛ*, *I*, ii. 17; *SiŚe*, iii. 63-64; *SiŚi*, *I*, ii. 47(ii).

[3] This rule is found also in *Ā*, iv. 24; *BrSpSi*, ii. 56; *LBh*, ii. 17; *ŚiDVṛ*, *I*, ii.18; *SiŚe*, iii. 66; *SiŚi*, *I*, ii. 48.

[4] This rule is found also in *Ā*, iv. 26; *LBh*, ii. 17-18; *SiŚe*, iii. 65.

[5] This rule is found also in *SūSi*, ii. 61; *BrSpSi*, ii. 57-58; *LBh*, ii. 18; *ŚiDVṛ*, *I*, ii. 18; *SiŚe*, iii. 67 (i); *SiŚi*, *I*, ii. 49 (i).

That is

(1) $\text{Rsin } \delta = \dfrac{1397 \times \text{Rsin } \lambda}{\text{R}}$,

(2) $\text{Day-radius} = \sqrt{\text{R}^2 - (\text{Rsin } \delta)^2}$,

(3) $\text{Earthsine} = \dfrac{\text{Rsin } \phi \times \text{Rsin } \delta}{\text{Rsin } (90° - \phi)}$,

(4) $\text{Rsin (ascensional difference)} = \dfrac{\text{earthsine} \times \text{radius}}{\text{day-radius}}$,

where R is the radius, $\phi$ is the latitude of the place, and $\lambda$ and $\delta$ are the *sāyana* longitude[1] and declination respectively.

*Definitions.*

The day-radius is the radius of the small circle parallel to the celestial equator. A small circle parallel to the celestial equator is called a diurnal circle (*ahorātra-vṛtta*). In particular, the Sun's diurnal circle is the small circle parallel to the equator which the Sun describes in the course of a day.

The earthsine is the Rsine of the arc of a diurnal circle intercepted between the local horizon and the six o'clock circle.[2] In Hindu astronomy the six o'clock circle is called the equatorial horizon (*nirakṣa-kṣitija*) as it is the horizon of a place[3] on the equator.

The ascensional difference is defined by the arc of the celestial equator lying between (i) the equatorial horizon and (ii) the secondary to the equator passing through the intersection of the diurnal circle and the (eastern or western) horizon. It is measured in time (i.e., in *asus*[4]). The ascensional difference of the Sun thus denotes the difference between the times of rising of the Sun on the local and equatorial horizons.

---

[1] By the *sāyana* longitude is meant the celestial longitude measured from the moving vernal equinox.

[2] The six o'clock circle is the great circle of the celestial sphere which passes through the east and west points of the celestial horizon and the poles of the celestial equator.

[3] This place lies at the intersection of the local meridian and the equator.

[4] One *asu* corresponds to one minute of arc of the celestial equtaro Thus one *asu* = 4 seconds of sidereal time.

*Rationale of the above rules.*

(1) In Fig. 4, let S be the Sun (or a point on the ecliptic), SL the perpendicular from S on the plane of the celestial equator, and SM the perpendicular from S on the line joining the centre of the celestial sphere with the first point of Aries. Then in the plane triangle SLM, we have

$$SL = R\sin\delta,$$
$$SM = R\sin\lambda,$$
$$\angle SML = \epsilon,$$
$$\text{and } \angle SLM = 90°.$$

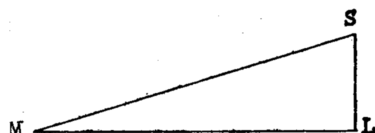


Fig. 4

Therefore, $SL/SM = R\sin\epsilon / R\sin 90°$,

or
$$R\sin\delta = \frac{R\sin\epsilon \times R\sin\lambda}{R}$$
$$= \frac{1397 \times R\sin\lambda}{R}, \text{ for } R\sin\epsilon = 1397'.$$[1]

(2) The arcual distance of the diurnal circle from the north pole of the celestial equator $= 90° - \delta$. Therefore, the day-radius $= R\sin(90° - \delta)$, or $\sqrt{R^2 - (R\sin\delta)^2}$.

(3) In Fig. 5, let K be the point of intersection of the diurnal circle and the six o'clock circle, KB the perpendicular from K on the rising-setting line,[2] and KA the perpendicular from K on the east-west line. Then in the plane triangle KAB, we have

$$KA = R\sin\delta,$$
$$KB = \text{earthsine},$$
$$\angle KBA = 90° - \phi,$$
$$\text{and } \angle KAB = \phi.$$

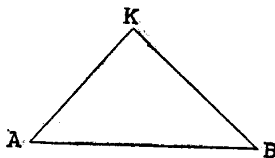


Fig. 5

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[1] See *LBh*, ii. 16.

[2] The rising-setting line of a heavenly body is the line joining the point where the heavenly body rises on the eastern horizon with the point where it sets on the western horizon. In other words, it is the line of intersection of the planes of the celestial horizon and the diurnal circle.

Therefore, we have

$$\frac{\text{earthsine}}{\text{Rsin } \delta} = \frac{\text{Rsin } \phi}{\text{Rsin } (90^\circ - \phi)},$$

$$\text{or} \quad \text{earthsine} = \frac{\text{Rsin } \phi \times \text{Rsin } \delta}{\text{Rsin } (90^\circ - \phi)}.$$

(4) By definition

$$\frac{\text{Rsin (asc. diff.)}}{\text{earthsine}} = \frac{\text{radius}}{\text{day-radius}}.$$

$$\text{Therefore} \quad \text{Rsin (asc. diff.)} = \frac{\text{earthsine} \times \text{radius}}{\text{day-radius}}.$$

A rule for finding the ascensional differences of the (*sāyana*) signs Aries, Taurus, and Gemini :

8. Twenty-four multiplied by ten (i.e., 240), 192, and 81—these when (successively) multiplied by the *aṅgulas* of the equinoctial midday shadow and (the products thus obtained) divided by four become the *asus* of the ascensional differences corresponding to Aries, Taurus, and Gemini respectively.[1]

The numbers 240, 192, and 81 given above are four times the ascensional differences in *asus* of the signs, Aries, Taurus, and Gemini respectively for a place having one *aṅgula* for the equinoctial midday shadow.

We have seen that the ascensional difference of the Sun is the difference between the times of rising of the Sun on the local and equatorial horizons. The ascensional difference of the sign Aries is the difference between the times that the sign Aries takes in rising above the local and equatorial horizons. Since the first point of Aries rises simultaneously at both the horizons, therefore the ascensional difference of Aries is equal to the ascensional difference of the last point of Aries (for which $\lambda=30^\circ$). Similarly, the ascensional difference of Aries and Taurus (taken together) is equal to the ascensional difference of the last point of Taurus (for which $\lambda=60^\circ$).

The ascensional difference of Taurus is equal to the ascensional difference of Aries and Taurus minus the ascensional difference of Aries.

[1] Similar rules occur also in *PSi*, iii. 10 ; *KK* (Sengupta), i. 21; *KK* (Babua Misra), iii. 1; *ŚiDVṛ*, *I*, xiii. 9; *SiŚi*, *I*, ii. 50-51.

That is to say, it is equal to the ascensional difference of the last point of Taurus minus the ascensional difference of the first point of Taurus.

The ascensional difference of Gemini, similarly, is equal to the ascensional difference of the last point of Gemini minus the ascensional difference of the first point of Gemini.

The following is the *rationale* of the above rule:

From stanza 7, we have

$$\text{Rsin (asc. diff.)} = \frac{\text{Rsin } \phi \times \text{Rsin } \delta}{\text{Rsin } (90^0 - \phi)} \times \frac{\text{radius}}{\text{day-radius}}.$$

But from stanza 5, assuming gnomon = 12 *aṅgulas,*

$$\frac{\text{Rsin } \phi}{\text{Rsin } (90^0 - \phi)} = \frac{\text{equinoctial midday shadow}}{12}.$$

Therefore

$$\text{Rsin (asc. diff.)} = \frac{(\text{equinoctial midday shadow}) \times \text{Rsin } \delta \times \text{radius}}{12 \times \text{Rcos } \delta}.$$

Hence for a place having one *aṅgula* for the equinoctial midday shadow

$$\text{Rsin (asc. diff.)} = \frac{\text{Rsin } \delta \times \text{R}}{12 \times \text{Rcos } \delta}$$

$$= \frac{1397 \times \text{Rsin } \lambda}{\text{R}} \times \frac{\text{R}}{12 \times \text{Rcos } \delta}, \text{ (using stanza 6)}$$

where $\lambda$ is the *sāyana* longitude, $\delta$ the declination, and R the radius (=3438′).

Now we will calculate the ascensional differences of Aries, Taurus, and Gemini for a place having one *aṅgula* for the equinoctial midday shadow.

(1) Calculation of the ascensional difference of Aries.

At the last point of Aries, $\lambda = 30^0$, so that Rsin $\lambda$ = R/2.

Therefore, Rsin $\delta' = 1397/2 = 698' \cdot 5$

and Rcos $\delta = 3366'$.

Hence Rsin (asc. diff. of Aries)

$$= \frac{698{\cdot}5 \times 3438}{3366 \times 12}$$

$$= \frac{2401443}{40392}$$

$$= 60' \text{ approx.}$$

Therefore, the ascensional difference of Aries is 60 *asus* approximately.

(2) Calculation of the ascensional difference of Taurus.

At the last point of Taurus, $\lambda = 60^0$, so that
$\text{Rsin } \lambda = 2977'$.

Therefore, $\text{Rsin } \delta = 1210'$ approx.
and $\text{Rcos } \delta = 3218'$ approx.

Hence Rsin (asc. diff. of Aries and Taurus)

$$= \frac{1210 \times 3438}{12 \times 3218}$$

$$= 108' \text{ approx.}$$

Therefore, the ascensional difference of Aries and Taurus is 108 *asus*. Subtracting from it the ascensional difference of Aries, the ascensional difference of Taurus comes out to be 48 *asus*.

(3) Calculatlon of the ascensional difference of Gemini.

At the last point of Gemini, $\lambda = 90^0$, so that $\text{Rsin}\,\lambda = \text{R}$. Therefore, $\text{Rsin } \delta = 1397'$ and $\text{Rcos}\,\delta = 3141'$.

Hence Rsin (asc. diff. of Aries, Taurus, and Gemini)

$$= \frac{1397 \times \text{R}}{12 \times 3141}$$

$$= \frac{4802886}{37692}$$

$$= 128' \text{ approx.}$$

It follows that the ascensional difference of Aries, Taurus, and Gemini (taken as a whole) is 128 *asus*. Subtracting from it the ascensional difference of Aries and Taurus, we get 20 *asus*. This is the ascensional difference of Gemini.[1]

The formula for the ascensional difference may now be written as

$$\text{Rsin (asc. diff.)} = \text{Rsin (asc. diff. for unit equinoctial midday shadow)} \times \text{(equinoctial midday shadow)}.$$

$$\text{or} \quad \text{asc. diff.} = \frac{[4 \times \text{(asc. diff. for unit equinoctial midday shadow)}] \times \text{(equinoctial midday shadow)}}{4}$$

approximately. Hence the above rule.

A rule for finding the times of rising of the (*sāyana*) signs at the equator :

9. (Severally) multiply the Rsines of (one, two, and three) signs by 3141 and divide (each of the products) by the corresponding day-radius. Reduce the resulting Rsines to the corresponding arcs, and then diminish each arc by the preceding arc (if any). The residues obtained after subtraction are the times (in *asus*) of rising of the signs Aries, Taurus, and Gemini at the equator.[2]

---

[1] We have taken above the approximate values of the ascensional differences of the last points of Aries, Taurus, and Gemini. Better values are 59·45, 107·77 and 127·4 *asus*. If these values are taken, then the ascensional differences of Aries, Taurus, and Gemini would come out to be 59·45, 48·32, and 19·63 *asus*. Four times of these are 238, 193 and 79 *asus* approx. Hence some astronomers (see Parameśvara's *Siddhānta-dīpikā*) give the following reading of the text:

वसुत्रिदस्रा (238) गुणरन्ध्रभूमयो (193)
नवाद्रव (79) श्चाभिहृता: पलाङ्गुलै: ।
हृताश्चतुर्भि: क्रियगोयमान्तजा-
श्चरासव: स्यु: क्रमशस्तु चापिता: ॥

[2] This rule is found also in *SūSi*, iii. 42-43; *BrSpSi*, iii. 15; *ŚiDVr*, *I*, iii. 8; *SiŚe*, iv. 15; *SiŚi*, *I*, ii. 51.

If A, B, and C be the last points of the signs Aries, Taurus, and Gemini respectively, then the time of rising of Aries at the equator is equal to the right ascension of A, the time of rising of Taurus at the equator is equal to the right ascension of B minus the right ascension of A, and the time of rising of Gemini at the equator is equal to the right ascension of C minus the right ascension of B.

If $\lambda$ and $\delta$ be the *sāyana* longitude and declination of a point on the ecliptic, then the right ascention $\alpha$ of that point is given by the formula :[1]

$$\text{Rsin}\,\alpha = \frac{\text{Rcos}\,\epsilon \times \text{Rsin}\,\lambda}{\text{Rcos}\,\delta},$$

where $\epsilon$ is the obliquity of the ecliptic.

But, according to Bhāskara I, $\epsilon = 24°$;[2] therefore we have

$$\text{Rsin}\,\alpha = \frac{3141 \times \text{Rsin}\,\lambda}{\text{day-radius}}.$$

Hence the above rule.

Times of rising of the (*sāyana*) signs, Aries, Taurus, and Gemini at the equator and a rule for finding the times of rising of the (*sāyana*) signs at the local place :

10. Those who know astronomical methods have found them (i.e., the times of rising of Aries, Taurus, and Gemini at the equator) to be 1670, 1795, and 1935 (*asus* respectively). These respectively diminished and the same reversed and increased by the corresponding ascensional differences are the times (in *asus*) of rising of the six signs beginning with Aries at the local place. (The same in the inverse order are the times of rising of the six signs beginning with Libra at the local place.)[3]

If *a*, *b*, and *c* denote the ascensional differences of Aries, Taurus and Gemini respectively, then the times of rising of the signs at the local place are given by the following table :

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[1] This formula occurs in *Ā*, iv. 25. For its *rationale* see Part I, Chapter IX.

[2] See *LBh*, ii. 16, where Rsin $\epsilon$ has been stated to be equal to 1397′.

[3] This rule occurs also in *SūSi*, iii. 43-45; *LBh*, iii. 5-6; *ŚiDVṛ*, *I*, iii. 9; *SiŚe*, iv. 17, 15(ii); *SiŚi*, *I*, iii. 58-59(i).

**Times of Rising of the Signs at the Local Place**

| Sign | Time of rising at the local place, in *asus* | Sign |
|---|---|---|
| 1 Aries | 1670 — *a* | 12 Pisces |
| 2 Taurus | 1795 — *b* | 11 Aquarius |
| 3 Gemini | 1935 — *c* | 10 Capricorn |
| 4 Cancer | 1935 + *c* | 9 Sagittarius |
| 5 Leo | 1795 + *b* | 8 Scorpio |
| 6 Virgo | 1670 + *a* | 7 Libra |

A rule for the determination of the meridian zenith distance and meridian altitude of the Sun with the help of the Sun's declination and the latitude of the place :

11. The difference or the sum of the Sun's declination and the latitude (of the place) according as the Sun is in the six signs beginning with Aries or in the six signs beginning with Libra is the Sun's meridian zenith distance (i.e., the zenith distance of the midday Sun).[1]

90 degrees (literally, a quadrant of a circle) minus the degrees of the (Sun's) meridian zenith distance is the (Sun's) meridian altitude.[2]

The Rsine of the degrees of the Sun's meridian zenith distance is the great shadow; and the other (i.e., the Rsine of the Sun's meridian altitude) is the great gnomon.

An alternative rule for finding the Sun's meridian altitude :

12. Or, take the Sum or difference of the earthsine and the day-radius according as the Sun is in the northern or southern

[1] This rule is found also in *BrSpSi*, iii. 47; *LBh*, iii. 27; *ŚiDVṛ*, *I*, iii. 16; *SiŚe*, iv. 42(i).

[2] This rule is found also in *BrSpSi*, iii. 47(ii); *SiŚe*, iv. 42(ii).

hemisphere; then multiply that (sum or difference) by (the Rsine of) the colatitude and divide by the radius. The result thus obtained is the Rsine of the Sun's altitude at midday.

Let S (See Fig. 6) be the position of the midday Sun on the celestial sphere. Also let SA and SB be the perpendiculars dropped from S on the plane of the celestial horizon and the Sun's rising-setting line[1] respectively. Then in the plane triangle SAB, we have

$$SA = \text{Rsin } a$$

$$SB = \text{day-radius} \pm \text{earthsine},$$

$$\angle SBA = 90° - \phi,$$

and $\angle SAB = 90°$,

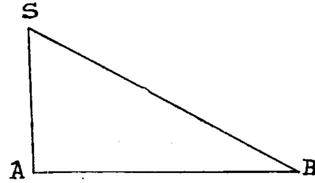



Fig. 6

where $a$ denotes the Sun's altitude, and $\phi$ the latitude of the place.

Therefore $$SA/SB = \text{Rsin } \angle SBA \,/\, \text{Rsin } \angle SAB,$$

or $$\text{Rsin } a = \frac{(\text{day-radius} \pm \text{earthsine}) \times \text{Rsin } (90° - \phi)}{R},$$

+ or — sign being taken according as the Sun is to the north or south of the equator.

A rule for determining the Sun's declination with the help of the Sun's meridian zenith distance and the latitude of the local place, when the latitude is greater than the Sun's meridian zenith distance:

13. When the latitude is greater than the arc of the Sun's meridian zenith distance derived from the (midday) shadow (of the gnomon), their difference is the declination of the apparent Sun. The Sun is also, in that case, in the northern hemisphere.[2]

This rule relates to the case when the midday shadow of the gnomon falls to the north of the gnomon.

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[1] *Vide supra*, p. 64 (footnote).

[2] This rule is found also in *LBh*, iii. 30.

A rule for determining the Sun's declination with the help of the Sun's meridian zenith distance and the latitude of the local place, when the midday shadow of the gnomon falls to the south of the gnomon :

14. When the (midday) shadow (of the gnomon) falls to the south (of the gnomon), then the sum of the latitude and the Sun's true meridian zenith distance gives the declination of the Sun lying in the northern hemisphere.[1]

A rule for finding the Sun's declination with the help of the latitude and the Sun's meridian zenith distance, when the Sun's meridian zenith distance is greater than the latitude and the shadow of the gnomon falls towards the north of the gnomon :

15. When the Sun's meridian zenith distance is greater than the latitude, then the latitude is always subtracted from that (i. e., from the Sun's meridian zenith distance): the remainder (obtained) after subtraction denotes the Sun's true declination. The Sun is also, in that case, undoubtedly in the southern hemisphere.[2]

The rules in the above three stanzas may be summarised as follows :

(1) When the midday shadow of the gnomon falls towards the north of the gnomon, then

Sun's declination = latitude $\sim$ Sun's meridian zenith distance,

the Sun's declination being north or south according as the latitude is greater or less than the Sun's meridian zenith distance.

(2) When the midday shadow of the gnomon falls towards the south of the gnomon, then

Sun's declination = latitude + Sun's meridian zenith distance,

the Sun's declination in this case being always north.

---

[1] This rule is found also in *LBh*, iii. 30.

[2] This rule is found also in *LBh*, iii. 31.

A rule for the determination of the Sun's longitude from its declination :

16. The radius multiplied by the Rsine of that (Sun's declination) should be divided by the Rsine of the Sun's greatest declination. The resulting Rsine reduced to arc, or (90° minus that arc) increased by three signs, or that (arc) increased by six signs, or (90° minus that arc) increased by nine signs, according as the Sun is in the first, second, third, or fourth quadrant, is the Sun's longitude.[1]

The longitude thus obtained is *sāyana*.

In the above rule a knowledge of the Sun's quadrant is assumed, but nowhere in the present work are we told how to know the Sun's quadrant. From other works on Indian astronomy we learn that it was known from the nature of the midday shadow. In the *Pitāmaha-siddhānta*[2] we are given the following criteria for knowing whether the Sun is in the first, second, third, or fourth quadrant :

"(When the Sun is) in the first quadrant, the (midday) shadow of the trees is smaller than the equinoctial midday shadow and also decreasing (day to day); in the second quadrant, it is smaller (than the same) but increasing; in the third quadrant, it is greater and also increasing; and in the fourth, it is greater but decreasing".

So also says Śrīpati[3], but (for places below the Tropic of Cancer) he adds :

"If the (midday) shadow fall towards the south and be on the increase, even then the quadrant is the first. Similarly, if you see that the (midday) shadow (falling towards the south) is on the decrease, you must understand that the quadrant is the second."[4]

---

[1] This rule occurs also in *SūSi*, iii. 18-19; and *LBh*, iii. 32-33.

[2] This work is in prose and was edited along with a few other *siddhāntas* in the *Joytiṣa-siddhānta-saṅgraha* by Pandit Vindhyeshwari Prasad Dwivedi, Banaras (1912).

[3] *SiŚe*, iv. 70.

[4] *SiŚe*, iv. 71.

Kamalākara has followed Śrīpati.[1] Parameśvara has also made a similar statement. He says:[2]

"The Sun's northern or southern hemisphere (*gola*) and the Sun's northerly or southerly course (*ayana*) should be determined from the point where the Sun rises and from the decrease or increase of the (midday) shadow (of a gnomon) on two consecutive days".[3]

Certain astronomers decided the Sun's quadrant on the basis of the seasons. For example, Bhāskara II writes :

"The quarters of the year are known from the characteristics of the seasons, so I will describe them afterwards".[4]

A rule for the determination of the latitude with the help of the Sun's meridian zenith distance and declination :

17. When the Sun is in the northern hemisphere (and the shadow of the gnomon falls towards the north), add the (Sun's) declination and the (Sun's) meridian zenith distance; when the Sun is in the southern hemisphere, or when the (midday) shadow (of the gnomon) falls towards the south (of the gnomon), take their difference: the sum or difference thus obtained is the latitude.[5]

A rule for finding the Rsine of the Sun's altitude or zenith distance from the time elapsed since sunrise in the forenoon or from the time to elapse before sunset in the afternoon :

18-20. Add the (Sun's) ascensional difference derived from the local latitude to or subtract that from the *asus* (elapsed since sunrise in the forenoon or to elapse before sunset in the afternoon) according as the Sun is in the southern or northern

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[1] See *SiTV*, iii. 192-193.

[2] अर्कस्योदयस्थानवशात् दिनद्वयोत्थयोश्छाययोर्न्यूनाधिकभावशाच्चाऽत्र गोलायने वेद्ये ।

[3] See Parameśvara's comm. on *SūSi*, ii. 19.

[4] *SiŚi*, *II*, xi. 38.

[5] This rule is found also in *SūSi*, iii. 15-16; *BrSpSi*, iii. 13; *LBh*, iii. 34; *SiŚe*, iv.13.

hemisphere. By the Rsine of that (sum or difference) multiply the day-radius and then divide (the product) by the radius. In the resulting quantity apply the earthsine reversely to the application of the ascensional difference (i.e., subtract the earthsine when the Sun is in the southern hemisphere and add the earthsine when the Sun is in the nothern hemisphere). Then multiply that (i.e., the resulting difference or sum) by the Rsine of the colatitude of the local place and then divide (the product) by the radius again. Thus is obtained the Rsine of the Sun's altitude for the given time in *ghaṭīs*.[1] The square root of the difference between the squares of the radius and that (Rsine of the Sun's altitude) is known as the (great) shadow.[2]

The *asus* elapsed since sunrise in the forenoon or to elapse before sunset in the afternoon are obtained by multiplying the given *ghaṭīs*[3] by 360. These are equivalent to the number of minutes in the arc of the celestial equator lying between the hour circles passing through the Sun and through the Sun's position on the horizon at sunrise or sunset. When these *asus* are diminished or increased by the *asus* of the Sun's ascensional difference (according as the Sun is in the northern or southern hemisphere), the *asus* of the difference or sum correspond to the minutes lying in the arc of the celestial equator intercepted between the Sun's hour circle and the six o'clock circle. The Rsine of that multiplied by the day-radius and divided by the radius gives the distance in minutes of the Sun from the line joining the points of intersection of the six o'clock circle and the Sun's diurnal circle. That increased or diminished by the earthsine (according as the Sun is in the northern or southern hemisphere) gives the distance of the Sun from the rising-setting line.

In Fig. 7, let S be the position of the Sun on the celestial sphere, SA the perpendicular from S on the plane of the horizon, and SB the perpendicular from S on the rising-setting line. Then in the plane triangle SAB, we have

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[1] This rule is found also in *Ā*, iv. 28; *BrSpSi*, iii. 25-26; *LBh*, iii. 7-10; *SiDVṛ*, *I*, iii. 24-25; *SiŚe*, iv. 32, 34; *SiŚi*, *I*, iii. 53-54.

[2] This rule is found also in *BrSpSi*, iii. 27(ii); and *SiŚe*, iv. 34.

$SA = R\sin a.$

$$SB = \frac{R\sin(\text{given time in } asus \mp \text{asc. diff.}) \times \text{day-radius}}{\text{radius}} \pm \text{earthsine},$$

$\angle SBA = 90^0 - \phi,$

and $\angle SAB = 90^0,$

where $a$ is the Sun's altitude, and $\phi$ the latitude of the place.

Therefore, we have

$$R\sin a = \frac{SB \times R\cos\phi}{R}.$$

Hence the rule.

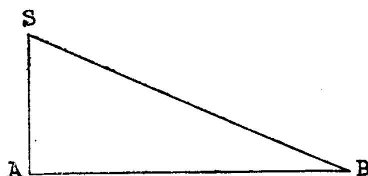



Fig. 7

An approximate rule for finding the Sun's altitude:

21. Multiply "the upright due to the instantaneous meridian-ecliptic point" by the Rsine of the degrees intervening between the Sun and the rising point of the ecliptic and then divide (the product) by the radius: the result is the Rsine of the Sun's true altitude. The square root of the difference between the squares of that and the radius is the Rsine of the Sun's zenith distance.

"The upright due to the meridian-ecliptic point" is the Rsine of the altitude of the meridian-ecliptic point.[1] Therefore, the rule stated above may be expressed as

$$R\sin a = \frac{R\sin\theta \times R\sin(L - S)}{R},$$

where $a$ is the Sun's altitude, $\theta$ the altitude of the meridian-ecliptic point, $L$ the longitude of the rising point of the ecliptic, $S$ the longitude of the Sun, and R the radius of the celestial sphere (= 3438′). The rising point of the ecliptic is that point of the ecliptic which lies on the eastern horizon.

This formula is approximate, because the distance between the rising point of the ecliptic and the meridian-ecliptic point is not always exactly equal to $90^0$ as assumed there.

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[1] See the next stanza.

The correct formula is

$$\text{Rsin } a = \frac{\text{Rsin } \psi \times \text{Rsin } (L-S)}{\text{R}},$$

where $\psi$ denotes the altitude of the central ecliptic point.[1]

The author does not prescribe this correct formula, because the value of Rsin $\psi$ has not been accurately determined by him. In Chapter V he gives only an approximate formula for it.[2]

For practical purposes the approximate formula is good enough.

Definition of "the upright due to the meridian-ecliptic point :"

22. The square root of the difference between the squares of the Rsine of the zenith distance of the meridian-ecliptic point and of the radius (*ravi-kakṣyā*) is called "the upright due to the meridian-ecliptic point" by those who are well versed in Spherics.

Thus we see that "the upright due to the meridian-ecliptic point" is the Rsine of the altitude of the meridian-ecliptic point. It is usually called *madhya-śaṅku*.

The word *ravi-kakṣyā*, literally meaning "the Sun's orbit", is used in the text in the sense of "the radius (of the Sun's orbit)".

Two alternative rules for finding the Sun's altitude :

23-24. Increase or diminish the *ghaṭīs* (elapsed since sunrise in the forenoon or to elapse before sunset in the afternoon) by the *asus* of the (Sun's) ascensional difference (according as the Sun is in the southern or northern hemisphere). To the Rsine of that apply the Rsine of the (Sun's) ascensional difference reversely to the above. By what

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[1] The central ecliptic point (also called the "nonagesimal") is that point of the ecliptic which is 90 degrees behind the rising point of the ecliptic and 90 degrees ahead of the setting point of the ecliptic. This point of the ecliptic is at the shortest distance from the zenith and is the central point of that part of the ecliptic which lies above the horizon.

[2] See *infra*, Chapter V, verse 19.

is thus obtained multiply the product of the day-radius and (the Rsine of) the colatitude and then divide (the resulting product) by the square of the radius. The result of this (operation) is the Rsine of the (Sun's) altitude.

Or, multiply the result obtained by the inverse application of Rsine of the (Sun's) ascensional difference (in the above process) by the product of (the length of) the gnomon and the day-radius and then divide by the product of (the length of the hypotenuse of the equinoctial midday shadow and the radius; the result is the Rsine of the (Sun's) altitude.[1]

That is to say,

$$\text{Rsin } a = \frac{M \times \text{day-radius}}{\text{R}} \times \frac{\text{Rcos } \phi}{\text{R}}, \qquad (1)$$

where $M = $ Rsin (given *ghaṭis*$\mp$asc. diff)$\pm$Rsin (asc. diff. ), the upper or lower sign being taken according as the Sun is in the northern or southern hemisphere. $a$ and $\phi$ are, as usual, the Sun's altitude and the latitude of the place respectively.

Or,

$$\text{Rsin } a = \frac{M \times \text{day-radius}}{\text{R}} \times \frac{\text{gnomon}}{\text{hypotenuse of equinoctial midday shadow}} \qquad \dots (2)$$

"$M$ multiplied by day-radius and divided by radius" represents in the celestial sphere the perpendicular distance of the Sun from the rising-setting line.

A rule for finding the Sun's altitude when the Sun's ascensional difference is greater than the given time:

25. When the (Sun's) ascensional difference (is greater than and) cannot be subtracted from the given *asus* (elapsed since sunrise in the forenoon or to elapse before sunset in the afternoon), subtract the latter from the former and with the Rsine of the remainder proceed as before (i.e., multiply that by the day-radius and divide by the radius); then subtract the resulting

[1] This rule occurs also in *BrSpSi*, iii. 27(i); *ŚiDVṛ*, *I*, iii. 27; *SiŚe*, iv. 37.

Rsine from the earthsine and then performing the usual process (i.e., multiplying that by the Rsine of the colatitude and dividing the product by the radius) determine the Rsine of the (Sun's) altitude.[1]

The case contemplated here arises when the Sun lies between the equatorial and local horizons, i.e., shortly after sunrise or before sunset.

A rule for finding the Sun's altitude in the night:

26. In the night, the Rsine of the Sun's altitude is to be obtained by applying the operations (of addition and subtraction) inversely, because the (laws of) addition and subtraction (of the Sun's ascensional difference and earthsine) in the night are contrary to those in the day.[2]

The Rsine of the Sun's altitude in the night is required (i) in the calculation of the elevation of lunar horns,[3] and (ii) in the calculation of the solar eclipse.[4]

The details of the method indicated in the above stanza have been explained by Parameśvara as follows:

"(When the Sun is) in the northern hemisphere, having calculated the Rsine of the given nocturnal *asus* (i.e., those elapsed since sunset in the first half of the night or those to elapse before sunrise in the second half of the night) as increased by the (Sun's) ascensional difference, (then) multiplying (that) by the day-radius and dividing by the radius, (then) from the (resulting) quotient subtracting the earthsine, and (finally) multiplying the remainder by the Rsine of the colatitude and dividing by the radius is obtained the Rsine of the Sun's altitude. (When the Sun is) in the southern hemisphere, the (Sun's) ascensional difference and the earthsine are (respectively) subtractive and additive: this is the difference."[5]

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[1] This rule is found also in *BrSpSi.* iii, 33; *LBh,* iii. 11; *ŚiDVṛ, I,* iii. 29; *SiŚe*, iv. 41.

[2] This rule is found also in *BrSpSi,* iii. 63: *LBh,* iii. 11; *SiŚe*, iv. 89.

[3] See *BrSpSi,* iii. 63.

[4] See Parameśvara's comm. on *LBh,* iii. 11.

[5] Parameśvara's comm. on *LBh.* iii. 11.

The Sun's altitude for the night has been called *pātāla-śaṅku* by Brahmagupta.[1]

Three rules for finding the time elapsed since sunrise in the forenoon or to elapse before sunset in the afternoon when the Sun has a given altitude :

27-29. Multiply the Rsine of the Sun's altitude derived from the given shadow (of the gnomon) by the radius and divide (the product) by (the Rsine of) the colatitude. Then subtract the minutes of the earthsine from or add them to the resulting quantity according as the Sun is in the six signs beginning with Aries or in the southern hemisphere. Multiply the resulting quantity by the radius and divide (the product) by the day-radius. To the corresponding arc apply the ascensional difference contrarily to the above: thus is obtained the number of *asus* (elapsed since sunrise in the forenoon or to elapse before sunset in the afternoon). These very same *asus* corresponding to the day to elapse (before sunset in the afternoon) or the day elapsed (since sunrise in the forenoon), when divided by 360, are declared to be the *nāḍīs*, etc., (of the required time).[2]

Or, multiply the given Rsine of the Sun's altitude by the square of the radius and divide by the product of the day-radius and (the Rsine of) the colatitude. To the result apply the Rsine of the (Sun's) ascensional difference as before (i.e., subtract or add according as the Sun is in the northern or southern hemisphere). Then to the corresponding arc reversely apply the *asus* of the ascensional difference: the result obtained is again the number of *asus* (elapsed since sunrise in the forenoon or to elapse before sunset in the afternoon.)

Or, multiply the Rsine of the Sun's altitude by the hypotenuse of the equinoctial midday shadow and again by the

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[1] See *BrSpSi*, xv. 9.

[2] This rule is found also in *LBh*, iii. 12-15 and in *SiŚe*, iv. 51-52.

radius and then divide (the resulting product) by the day-radius as multiplied by (the length of) the gnomon. From that the process for the determination of the (desired time in) *nāḍīs* is the same as before.

The first rule is the converse of the rule given in stanzas 18-20; the second rule is the converse of that given in stanza 23; and the third rule is the converse of that stated in stanza 24.

A rule for finding the longitude of the rising point of the ecliptic with the help of (i) the instantaneous *sāyana* longitude of the Sun and (ii) the civil time measured since sunrise, or with the help of (i) the Sun's *sāyana* longitude at sunrise and (ii) the sidereal time elapsed since sunrise :

30-32. Multiply by the untraversed portion of (the sign occupied by) the Sun, the *asus* of the oblique ascension (i.e., the time, in *asus*, of rising at the local place) of that sign and divide (that product) by the number of degrees or minutes in a sign (i.e., by 30 or 1800) (according as the untraversed portion of the Sun's sign is taken in degrees or minutes). Thus are obtained the *asus* of the oblique ascension of the untraversed portion of the sign occupied by the Sun. Subtract these from the given (time as reduced to) *asus* ; and add the untraversed portion of the Sun's sine to the Sun's longitude (which is given). Then from the remaining *asus* subtract the *asus* of the oblique ascension of as many (succeeding) signs as possible; and add the same number of signs to the Sun's longitude. Then multiply the outstanding residue of the given (time in) *asus* by 30 and divide (the product) by the *asus* of the oblique ascension of the next sign. Add the resulting degrees, etc., to the Sun's longitude (obtained above). The resulting longitude is stated to be the (*sāyana*) longitude of the rising point of the ecliptic.[1]

[1] This rule in found also in *SūSi*, iii. 46-48; *BrSpSi*, iii. 18-20; *LBh*, iii. 17-19; *ŚiDVṛ*, *I*, iii. 11-12; *SiŚe*, iv. 18-19(i); *SiŚi*, *I*, iii. 2-4. The rising point of the ecliptic is that point of the ecliptic which lies on the eastern horizon.

It may be pointed out that the civil time elapsed since sunrise is equal to the sidereal time measured by the arc of the celestial equator lying between the hour circles which pass through the instantaneous position of the Sun and through the rising point of the ecliptic.

For greater accuracy in the result, Āryabhaṭa II (c. 950 A. D.) and Bhāskara II (1150 A. D.) prescribed the use of oblique ascensions of every 10 degrees of the ecliptic in place of those for every 30 degrees. Later on Muniśvara (1646 A.D.) and Kamalākara (1658 A. D.) prescribed the use of oblique ascensions of every degree of the ecliptic. Theoretically accurate method for getting the longitude of the rising point of the ecliptic was given earlier by the Kerala mathematician Nīlakaṇṭha (1500 A. D.).[1]

A rule for the determination of the longitude of the setting point of the ecliptic :

33. The longitude of the horizon-ecliptic point in the east[2] increased by half a circle (i.e., by 180°) is the longitude of the setting point of the ecliptic[3]. For, the time of setting of a sign is equal to the time taken in rising by the then rising sign.[4]

Bhāskara II also says:

"The time in which a sign rises (above the horizon), is the same as that in which the seventh sign sets (below the horizon)."[5]

A rule for obtaining the civil time measured since sunrise with the help of (i) the Sun's instantaneous *sāyana* longitude and (ii) the *sāyana* longitude of the rising point of the ecliptic, or the sidereal time elapsed since sunrise with the help of (i) the Sun's *sāyana* longitude at sunrise and (ii) the *sāyana* longitude of the rising point of the ecliptic:

34-36. Multiply the degrees of the traversed portion of the sign occupied by the rising point of the ecliptic by the

[1] His method occurs in *TS*, iii. 155(ii)-164(i).

[2] i.e., the rising point of the ecliptic.

[3] The setting point of the ecliptic is that point of the eclipti which lies on the western horizon.

[4] *Cf. ŚiDVṛ, I*, iii. 13(i); *SiŚi, I*, ii. 59(ii).

[5] *SiŚi, I*, ii. 59 (ii).

oblique ascension of that sign and divide by 30, the resulting *asus* denote the *asus* of the oblique ascension of the traversed portion of the sign occupied by the rising point of the ecliptic. (Also subtract the traversed portion of the sign occupied by the rising point of the ecliptic from the longitude of the same point). Then from the resulting longitude subtract as many preceding signs as there are up to the Sun; and find out the *asus* of the oblique ascensions of those signs. These *asus* together with those (obtained above) when added with the *asus* of the oblique ascension of the untraversed portion of the Sun's sign give the *asus* (elapsed since sunrise) in the day and (enable us to know) the *asus* (elapsed since sunset) in the night. Dividing them by 6 and then by 60 are obtained the *ghaṭīs*, *vighaṭīs*, and *asus* (of the time elapsed during the day or night).[1]

This rule is the converse of that given in stanzas 30-32. It actually gives the method for finding the time elapsed since sunrise. When, therefore, the Sun's longitude is given for sometime in the night and it is required to find the time elapsed since sunset, then the time elapsed since sunrise obtained according to the above rule should be diminished by the length of that day, or, as says the commentator Parameśvara, the given longitude of the Sun should be increased by six signs and then should be applied the above rule.

In case the given quantities be (i) the longitude of the rising point of the ecliptic and (ii) the Sun's longitude at sunrise and the problem be to find out the civil time elapsed since sunrise, the above rule should be applied by treating the Sun's longitude for sunrise as the first approxi-

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[1] This rule is found also in *SūSi*, iii. 50-51; *BrSpSi*, iii. 21-23; *LBh*, iii. 20; *ŚiDVṛ*, *I*, iii. 13; *SiŚe*, iv. 19(ii)-22(i); *SiŚi*, *I*, iii. 5-7(i). The *ghaṭīs*, *vighaṭīs*, and *asus* are related by the following relations:

1 *asu* = 4 seconds,
6 *asus* = 1 *vighaṭī* (=24 seconds),
60 *vighaṭīs* = 1 *ghaṭī* (=24 minutes),

mation to the instantaneous longitude of the Sun. The process should then be repeated over and over again with the help of the successive approximations to the Sun's instantaneous longitude calculated after each round of the operation. The process should be continued until two successive approximations to the required time agree to *asus*.[1]

It must be noted that the longitudes used in this and the preceding rule (stated in stanzas 30-32) are all *sāyana*.

A rule for the determination of the Rsines of the Sun's prime vertical altitude and zenith distance :

37-38. Multiply the Rsine of the (Sun's) greatest declination by the Rsine of the Sun's true (*sāyana*) longitude; then divide (the product) by the Rsine of the colatitude : the result is (the Rsine of) the *agrā* of the true Sun.[2] When that (*agrā*) is less than the latitude and when the Sun is also in the northern hemisphere, multiply (the Rsine of the Sun's *agrā*) by (the Rsine of) the colatitude and then divide (the product) by the Rsine of the latitude : the result is the Rsine of the Sun's prime vertical altitude.[3] The square root of the difference between the squares of that and the radius is the Rsine of the Sun's (prime vertical) zenith distance.[4]

The Sun's *agrā* is the amplitude of the Sun at rising or setting. It is defined to be the arc of the celestial horizon lying between the east-west and rising-setting lines. That is to say, it is the arc of the celestial horizon lying between the east point and the point where the Sun rises or between the west point and the point where the Sun sets.

The Rsine of the Sun's *agrā* is equal to the distance between the east-west and rising-setting lines.

In Fig. 8, let S be the Sun on the prime vertical, SA and SB the perpendiculars from S on the east-west and rising-setting lines

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[1] *Cf. BrSpSi*, iii. 21-23; *SiŚi, I*, iii. 6(ii).
[2] This rule occurs also in *Ā*, iv, 30; *LBh*, iii. 21; *SiŚe*, iv. 58.
[3] This rule occurs also in *Ā*, iv. 31; *BrSpSi*, iii. 52; *LB*h, iii. 52.
[4] *Cf. LBh*, iii. 22.

respectively, and C the point where SB meets the line joining the points of intersection of the Sun's diurnal circle and the six o'clock circle. Naturally, SB is perpendicular to that line.

In the triangle ACB, we have

$$\begin{aligned} AC &= \text{Rsin } \delta, \\ AB &= \text{Rsin (Sun's } agr\bar{a}\text{)}, \\ \angle ABC &= 90° - \phi, \\ \text{and } \angle ACB &= 90°, \end{aligned}$$

where $\delta$ is the declination of the Sun, and $\phi$ the latitude of the place.

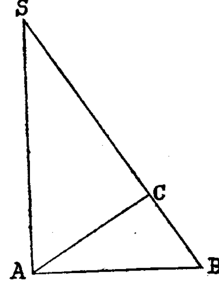



Fig. 8

Therefore

$$\text{Rsin (Sun's } agr\bar{a}\text{)} = \frac{\text{Rsin } \delta \times \text{R}}{\text{Rcos } \phi}.$$

But (*vide* stanza 6 above)

$$\text{Rsin } \delta = \frac{\text{Rsin } \lambda \times 1397}{\text{R}}.$$

Therefore

$$\text{Rsin (Sun's } agr\bar{a}\text{)} = \frac{\text{Rsin } \lambda \times 1397}{\text{Rcos } \phi}. \qquad (1)$$

where $\lambda$ is the Sun's *sāyana* longitude.

Now in the triangle SAB, right-angled at A, we have

$$\begin{aligned} SA &= \text{Rsin } a, \\ AB &= \text{Rsin (Sun's } agr\bar{a}\text{)}, \\ \text{and } \angle SBA &= 90° - \phi. \end{aligned}$$

Therefore

$$\text{Rsin } a = \frac{\text{Rsin (Sun's } agr\bar{a}\text{)} \times \text{Rcos } \phi}{\text{Rsin } \phi}, \qquad (2)$$

where $a$ is the Sun's altitude.

The necessary conditions for the existence of the prime vertical altitude of the Sun are: (i) that the Sun should be in the northern hemisphere, and (ii) that the Sun's declination should be less than the latitude of the place. The condition laid down in the above rule that the Sun's *agrā* should be less than the latitude is incorrect. This error is, in fact, due to Āryabhaṭa I,[1] whom the author is following in this work. But the

[1] See *Ā*, iv. 30-31.

author seems to be unaware of the error. For, in his later work, the *Laghu-Bhāskarīya*[1], he has rectified the error and has stated the condition correctly.

The above error of Āryabhaṭa I was noticed and criticised by Brahmagupta.[2] The commentators of Āryabhaṭa I, however, have interpreted the above rule as conveying the correct meaning.

A rule for the determination of the time in *asus* to elapse before or elapsed since midday when the Sun is on the prime vertical, i.e., the time taken by the Sun in going from the prime vertical to the local meridian or *vice versa* :

39. Multiply the Rsine of the Sun's longitude (when the Sun is on the prime vertical) by the Rsine of the (Sun's) greatest declination and divide (the product) by the day-radius: by the result thus obtained multiply the Rsine of the colatitude and (then) divide by the Rsine of the latitude. Subtract the square of the resulting quantity from the square of the radius: the arc corresponding to the square root of that gives the *asus* (measured on the equator from the Sun's hour circle) up to the meridian.

Let *m* denote the minutes in the arc of the Sun's diurnal circle intercepted between the Sun and the six o'clock circle, and r (= Rcos $\delta$) the radius of the Sun's diurnal circle. Then in Fig. 8, SC = rsin *m*; so that from the triangle SCA, right-angled at C, we have

$$\frac{SC}{CA} = \frac{\text{Rsin} \angle SAC}{\text{Rsin} \angle CSA}$$

$$\text{or,} \quad \text{rsin } m = \frac{\text{Rsin } \delta \times \text{Rcos } \phi}{\text{Rsin } \phi}$$

$$= \frac{\text{Rsin } \lambda \times \text{Rsin } \epsilon}{\text{R}} \cdot \frac{\text{Rcos } \phi}{\text{Rsin } \phi}, \text{ (using stanza 6)}$$

where $\lambda$, $\delta$ denote the Sun's *sāyana* longitude and declination respectively, and $\phi$ denotes the latitude of the place; $\epsilon$ is the Sun's greatest declination.

[1] iii. 22.

[2] See *BrSpSi*, xi. 22.

Therefore, the Rsine of the corresponding arc of the equator, i. e.,

$$\text{Rsin } m = \frac{\text{Rsin } \lambda \times \text{Rsin } \epsilon}{\text{r}} \times \frac{\text{Rcos } \phi}{\text{Rsin } \phi},$$

$$= \frac{\text{Rsin } \lambda \times \text{Rsin } \epsilon}{\text{day-radius}} \times \frac{\text{Rcos } \phi}{\text{Rsin } \phi},$$

so that

$$\text{Rsin } (90^0 - m) = \sqrt{\text{R}^2 - (\text{Rsin } m)^2}.$$

Therefore,

$$5400' - m = \text{Rsin}^{-1} [\text{Rsin } (90° - m)],$$

which gives the required time in *asus,* because $5400' - m$ is the number of minutes in the arc of the equator lying between the Sun's hour circle and the local meridian.

An alternative rule:

40. Or, multiply the Rsine of the Sun's prime vertical zenith distance by the radius and divide by the day-radius. Then applying the method of finding out the arc (corresponding to a given Rsine), convert the resulting Rsine into (the corresponding) arc. Then reduce the *asus* (thus obtained) to *nāḍīs*, etc. These lie between the (prime vertical) Sun and the meridian.

In Fig. 9, let S be the Sun on the prime vertical, B the centre of the Sun's diurnal circle, and A the point where the plane of the Sun's diurnal circle intersects the zenith-nadir line. Then in the plane triangle SAB, we have

SA = Rsin $z$,
SB = day-radius,
∠SAB = 90°,
and ∠SBA = the angle between the Sun's hour circle and the local meridian, $z$ being the Sun's zenith distance.
= arc of the equator intervening between the Sun's hour circle the local meridian.

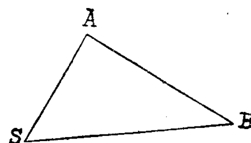


Fig. 9

Therefore, we have

$$\text{Rsin } \angle\text{SBA} = \frac{\text{Rsin } z \times \text{R}}{\text{day-radius}}.$$

A rule for finding the Sun's longitude when the Sun is on the prime vertical:

41. Multiply the Rsine of the latitude by the Rsine of the prime vertical altitude derived from the shadow (of the gnomon) and always divide the product by the Rsine of the Sun's greatest declination;(then reduce the resulting Rsine to the corresponding arc). The arc thus obtained, or(the complement of) that arc increased by three signs is the longitude of the (prime vertical) Sun (according as the Sun is in the first or the second quadrant). This is in accordance with what (Ārya)bhaṭa has written.[1]

That is to say, if $\lambda$ and $a$ be respectively the *sāyana* longitude and altitude of the Sun when it is on the prime vertical, and $\phi$ the latitude of the place, then

$$\text{Rsin } \lambda = \frac{\text{Rsin } a \times \text{Rsin } \phi}{\text{Rsin } \epsilon},$$

where $\epsilon$ is the Sun's greatest declination.

The *rationale* of this rule is as follows : Referring to Fig. 8, we see that in the triangle SAC

$$\begin{aligned} \text{SA} &= \text{Rsin } a, \\ \text{AC} &= \text{Rsin } \delta, \\ \angle \text{ACS} &= 90^\circ, \\ \text{and} \quad \angle \text{ASC} &= \phi. \end{aligned}$$

Therefore

$$\text{Rsin } \delta = \frac{\text{Rsin } a \times \text{Rsin } \phi}{\text{R}}. \qquad (1)$$

Also from stanza 6, we have

$$\text{Rsin } \lambda = \frac{\text{Rsin } \delta \times \text{R}}{\text{Rsin } \epsilon}. \qquad (2)$$

Hence, eliminating Rsin $\delta$ between (1) and (2), we get

$$\text{Rsin } \lambda = \frac{\text{Rsin } a \times \text{Rsin } \phi}{\text{Rsin } \epsilon}.$$

The next eleven stanzas relate to the determination of the locus of the end of the shadow of the gnomon.

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[1] *Cf. LBh*, iii. 24-25.

To determine at any given time three points lying on the locus of the shadow-end :

42-45. Determine the *agrā* and *śaṅkvagra* of the Sun and also the shadow (of the gnomon) for the desired time. Then take the sum of the two *agrās* (i.e., of *agrā* and *śaṅkvagra*) provided that they are of like direction[1] ; in the contrary case, take their difference. (This sum or difference is called the *bhuja* and its direction corresponds to that of the Sun from the prime vertical.) By that (sum or difference) multiply the shadow and divide (the product) by the Rsine of the Sun's zenith distance (for that time). Whatever is thus obtained should be laid off from the centre in the contrary direction (i.e., contrary to the direction of the Sun from the prime vertical) within a circle (drawn on level ground and) marked with the directions. Through the fish-figure drawn about the point thus obtained stretch out a thread in the east and west directions (bothways) to a distance. Then take a thread equal in length to the shadow (of the gnomon) and lay it off from the centre obliquely (to meet the other thread). Mark the two points where the end of this thread meets (the other thread stretched out) in the east and west directions. At the end of the midday shadow take a third point.

The sum or difference of the *agrā* and *śaṅkvagra*[2] of the Sun denotes the distance of the Sun's projection on the plane of the horizon from the east-west line. This is called the *bhuja* and its direction is the same as that of the Sun from the prime vertical. This multiplied by the length of the shadow of the gnomon and divided by the Rsine of the Sun's zenith distance gives the distance of the end of the shadow of the gnomon from the east-west line. Suppose, for example, that the sun is towards the south of the prime vertical, and that the end of the shadow of the gnomon is at a distance *d* from the east-west line.

Let the circle in Fig. 10 be the one constructed on level ground with

[1] The *agrā* is north or south according as it is towards the north or south of the east-west line; the *śaṅkvagra* is always south.

[2] For *agrā* see *supra* stanzas 37-38, and for *śaṅkvagra* see *infra* stanza 54.

the foot of the gnomon as centre and any arbitrary radius. Let EW and NS be the east-west and north-south lines respectively. Then the construction stated in the text is as follows : From O, along ON, measure a distance *d* and mark there a point, say X. Through X stretch a thread (or draw a line) parallel to EW. Let this be LM. Now from centre O and radius equal to the shadow of the gnomon draw an arc of a circle cutting LM at the points A and B. Then OA and OB are the positions of the threads, equal in length to the shadow of the gnomon, laid off obliquely from the centre. The two points thus obtained are A and B. If OC be the midday shadow of the gnomon, then the thirdp oint is C. The three points thus determined are A, B, and C.

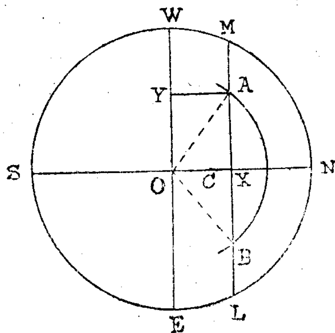


Fig. 10

A rule for determining the same three points when the directions are not known:

46-51. For one who does not know the directions with regard to the centre but wants to determine the directions and the locus of (the end of) the shadow (of the gnomon), I state the method such that (the end of) the shadow (cf the gnomon) may not leave the periphery of the large circle distinctly drawn amidst the directions (representing the path of the shadow-end).

Calculate the Rsine of the Sun's zenith distance, the Rsine of the Sun's altitude, and the *śaṅkvagra* corresponding to the desired shadow; then take the difference or sum of the two *agrās* (i.e., of the *śaṅkvagra* and the *agrā*) (according as they are of unlike or like directions). This (difference or sum) is the base, the Rsine of the Sun's zenith distance is the hypotenuse, and the square root of the difference between their squares is called the upright corresponding to the hypotenuse equal to the Rsine of the Sun's zenith distance. On multiplying these, upright and base, (severally) by the (length of the) shadow and dividing by the Rsine of the Sun's zenith distance are obtained

the values of the upright and the base (corresponding to the hypotenuse equal to the shadow of the gnomon). Now take straight bamboo scales of breadth equal to the diameter of the gnomon and of lengths equal to the base and the upright (obtained above) (and one equal to the shadow); and with their help construct an accurate framework instrument in the form of a rectangle or a (right-angled) triangle having the shadow (of the gnomon) for the hypotenuse. At the corner (where the base and the hypotenuse meet) fix a gnomon. Then put the instrument (on level ground) and rotate it (about the gnomon) until the shadow (of the gnomon) falls along the hypotenuse. Then having determined the directions (north and south, east and west) as indicated by the base and the upright, mark two points at the end of the shadow-hypotenuse (one towards the east and the other towards the west). At the end of the midday shadow, take the third point.

The above stanzas give the method for finding the points A, B, and C (see Fig. 10), when the lines EW and NS are not known. The method is as follows :

Construct a triangular frame of bamboo scales having its sides equal to those of the triangle AXO or a rectangular frame having its sides equal to those of the rectangle OXAY, and let a gnomon (having its diameter equal to the breadth of the bamboo scales) be fitted at O vertically to the frame.

Place the frame on level ground with the point O at the centre of a circle drawn on the ground and with the hypotenuse OA in coincidence with the shadow of the gnomon. Then OX is directed south to north and AX west to east. Draw the lines OX and AX on the ground and produce them bothways. With centre O and radius equal to OA, the shadow of the gnomon, draw an arc of a circle cutting the line AX at two points. These are the points A and B. The point C is obtained as before.

Construction of the locus of the end of the shadow of a gnomon:

52. Through all the three points (thus obtained) a circle is (then) drawn with the help of two fish-figures. The shadow (of the

gnomon) moves, like a spell-bound serpent, with its head (i.e., end) kept upon the periphery of that circle.[1]

Lalla says:

"With the point of intersection of the head-tail lines (of the two fish-figures) as centre, draw a circle passing through the ends of the three shadows. (The end of) the shadow (of the gnomon) does not leave the periphery of that circle in the same way as a lady born in a noble family does not leave the traditions of her family."[2]

Śrīpati (c. 1039 A. D.) writes:

"The (end of the) shadow of the gnomon erected at the centre of the circle does not leave the periphery of the circle drawn with the common point of the head and tail lines (of the two fish-figures) and passing through the three shadow-ends in the same way as a noble-minded person does not leave the path of righteousness."[3]

The above rule was later criticised by Bhāskara II (1150 A. D.), who made the following remark:

"It is declared (by some astronomers) that the shadow of the gnomon moves on the circle passing through the ends of the three shadows made by the same gnomon (placed in the centre of the horizon), but this is wrong, and consequently the east-west and north-south lines, the latitude, etc., found by the aid of the circle just mentioned are also wrong".[4]

Bhāskara II's criticism is proper. The locus of the end of the shadow of a gnomon will not be a circle as stated in the text unless the latitude of the place is 90°. The locus will be, in general, a conic section. For places whose latitudes are less than $\epsilon$ ($\epsilon$ being the obliquity of the ecliptic), in particular, this locus will be a hyperbola.

Alternative rules for finding the Sun's *agrā* and the latitude of the place:

53. The squareroot of the sum of the squares of the

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[1] This rule occurs also in *BrSpSi*, iii. 2-3; *ŚiDVṛ*, *I*, iii. 3; *SiŚe*, iv. 5; *TS*, iii. 42(ii)-47.

[2] *ŚiDVṛ*, *I*, iii. 3.

[3] *SiŚe*, iv. 5.

[4] L. Wilkinson, *Translation of the Siddhānta-śiromaṇi* (*Golādhyāya*, xi. 38(ii), Calcutta (1861), p.221. We have replaced the word "revolves" by "moves".

Rsine of the (Sun's) declination and the earthsine for the desired time is (the Rsine of) the Sun's *agrā* (for that time).

The earthsine multiplied by the radius and divided by (the Rsine of) the Sun's *agrā* is the Rsine of the latitude.

That is

$$\text{Rsin (Sun's } agr\bar{a}) = \sqrt{(\text{Rsin } \delta)^2 + (\text{earthsine})^2}, \quad (1)$$

$$\text{and} \quad \text{Rsin } \phi = \frac{\text{earthsine} \times \text{R}}{\text{Rsin (Sun's } agr\bar{a})}, \quad (2)$$

where $\delta$ is the Sun's declination and $\phi$ the latitude of the place.

These results easily follow from the triangle ACB in Fig. 8.

A rule for the determination of the *śaṅkvagra* :

54. The Rsine of the altitude for the desired time multiplied by the Rsine of the latitude and divided by (the Rsine of) the colatitude is the *śaṅkvagra*, which is always south (of the rising-setting line).[1]

The *śaṅkvagra* (of a heavenly body) is the distance of the projection of the heavenly body on the plane of the horizon from its rising-setting line. In Fig. 8, the line AB denotes the Sun's *śaṅkvagra*. The *śaṅkvagra* is measured from the rising-setting line and is always to the south of that line. It is more commonly known a *śaṅkutala*.

In Fig. 8, we have

$$\text{SA} = \text{Rsin } a,$$
$$\text{AB} = \acute{s}a\dot{n}kvagra,$$
$$\angle \text{SAB} = 90^0,$$
$$\text{and } \angle \text{SBA} = 90^0 - \phi,$$

where $a$ denotes the altitude, and $\phi$ the latitude of the place. Therefore from the triangle SAB, we have

$$\frac{\acute{s}a\dot{n}kvagra}{\text{Rsin } a} = \frac{\text{Rsin } \phi}{\text{Rcos } \phi},$$

which gives the formula stated in the text.

A rule for finding the equinoctial midday shadow:

55. Multiply the *śaṅkvagra* by 12 and divide by the Rsine of the altitude: the result is (the length of) the equinoctial

[1] This rule occurs also in *Ā*, iv. 29 and in *LBh*, iii. 16.

(midday) shadow (of the gnomon). The details are being stated below.

We have proved above (stanza 54) that

$$\frac{\acute{s}a\dot{n}kvagra}{\text{Rsin } a} = \frac{\text{Rsin } \phi}{\text{Rcos } \phi}.$$

Also, from stanza 5 above, we have

$$\frac{\text{Rsin } \phi}{\text{Rcos } \phi} = \frac{\text{equinoctial midday shadow}}{12}.$$

Therefore

$$\text{equinoctial midday shadow} = \frac{\acute{s}a\dot{n}kvagra \times 12}{\text{Rsin } a}.$$

Method of finding the Sun's *agrā* by observation and deriving therefrom the *śaṅkvagra* and then the equinoctial midday shadow of the gnomon and the latitude or colatitude of the place:

56-60(i). One should erect a (circular) platform, as high as one's neck, with its floor in the same level, and its circumference graduated with the divisions of signs, degrees, etc., and bearing the marks of the directions. (Then standing) on the western side thereof, one, having undisturbed state of mind, should, with the line of sight passing through the centre of the circular base, make the observation of the Sun when (at sunrise) it appears clinging to the circumference, (and mark there a point). The (arcual) distance, measured along the circumference graduated with the marks of degrees, between the end of the line drawn eastwards (i.e., the east point) and the point where the Sun is observed is the arc of the Sun's *agrā*. The Rsine of that (arc) is (the Rsine of) the Sun's *agrā*. The minutes of the difference between that (Rsine of the Sun's *agrā*) and the Rsine of the Sun' meridian zenith distance are the minutes of the *śaṅkvagra*, provided that the Sun is in the southern hemisphere; when the Sun is in the northern hemiphere (and the shadow of the gnomon falls towards the north), the process is otherwise (i.e., the addition of the two). When, however, (the Sun being in the northern hemisphere) the

shadow (of the gnomon) due to the Sun falls towards the south, the Sun's *agrā* minus the Rsine of the Sun's meridian zenith distance is stated to be (the value of) the *saṅkvagra*. From that (*śaṅkvagra*) determine the true value of the equinoctial midday shadow (of the gnomon),[1] and then calculate as before the latitude and colatitude (for the place).

A rule for finding the longitude of an unknown planet with the help of (i) the longitude of a known planet and (ii) the difference between the times of rising or setting of the known and unknown planets:

60(ii)-61. Having correctly ascertained in terms of *nāḍikās* (i.e., *ghaṭīs*) the difference between (the times of rising or setting or culmination of) the planets to be known and known, multiply those *ghaṭīs* by six. Thus are obtained the degrees (of the difference between the longitudes of the two planets). By those degrees diminish or increase the longitude of the known planet according as it is to the east or west of the planet to be known. This is stated by the learned people well versed in planetary motions (to be the method for getting the the longitude of the planet to be known).

This rule is approximate, as the inclinations of the orbits of the two planets to the ecliptic have been neglected and the ecliptic has been supposed to rise above the horizon uniformly at the rate of six degrees per *ghaṭī* (i.e., 15 degrees per hour).

## (2) JUNCTION-STARS OF THE ZODIACAL ASTERISMS AND CONJUNCTION OF PLANETS WITH THEM.

Longitudes of the prominent stars of the *nakṣatras*:

62. In this way from (the known longitudes of) the planets or stars have been determined, at all places and at all times, the celestial longitudes of the (prominent) stars of the *nakṣatras*.

The *nakṣatras* are the twenty-seven zodiacal asterisms. In the following table we give a few details regarding these *nakṣatras*.

[1] *Vide supra* stanza 55.

**Names, Shapes, and Number of the Stars of the *Nakṣatras***

| Name | Shape[1] | Number of stars as given by | | | Identification[5] |
|---|---|---|---|---|---|
| | | Varāha-mihira[2] | Brahma-gupta[3] | Lalla[4] | |
| Aśvinī | Head of a horse | 3 | 2 | 3 | $\alpha$, $\beta$, $\gamma$ Arietis |
| Bharaṇī | *Yoni*[6] | 3 | 3 | 3 | 35, 39, 41 Arietis |
| Kṛttikā | Razor | 6 | 6 | 6 | $\eta$ Tauri, etc. (Pleiades) |
| Rohiṇī | Cart | 5 | 5 | 5 | $\alpha$, $\theta$, $\gamma$, $\delta$, $\epsilon$, Tauri (Hyades) |
| Mṛgaśirā | Head of a deer | 3 | 3 | 3 | $\lambda$, $\phi_1$, $\phi_2$ Orionis |
| Ārdrā | Jewel | 1 | 1 | 1 | $\alpha$ Orionis |
| Punarvasu | House | 5 | 2 | 4 | $\beta$, $\alpha$ $i$, $v$, $\mu$ Geminorum |
| Puṣya | Arrow-head | 3 | 1 | 3 | $\theta$, $\delta$, $\gamma$ Cancri |
| Āśleṣā | Wheel | 6 | 6 | 5 | $\epsilon$, $\delta$, $\sigma$, $\eta$, $\rho$ Hydrae |
| Maghā | House | 5 | 6 | 5 | $\alpha$, $\eta$, $\gamma$, $\zeta$, $\mu$, $\epsilon$ Leonis |
| Pūrvā Phālgunī | *Mañca*[7] | 8 | 2 | 2 | $\delta$, $\theta$ Leonis |
| Uttarā Phālgunī | Cot | 2 | 2 | 2 | $\beta$, 93 Leonis |
| Hasta | Hand | 5 | 5 | 5 | $\delta$, $\gamma$, $\epsilon$, $\alpha$, $\beta$ Corvi (Corvus) |

[1] *MuCi*, ii. 59-60.
[2] *BṛSaṁ*, xcvii. 1-2.
[3] *KK* (Sengupta's edition), *x*. 1-2.
[4] *Ratna-Koṣa*.
[5] E. Burgess, *Translation of the Sūrya-Siddhānta*, Calcutta (1935), p. 378.
[6] i.e., the femal organ of generation.
[7] *Mañca* means an elevated platform resting on columns,

| Name | Shape | Number of stars as given by | | | Identification |
|---|---|---|---|---|---|
| | | Varāha-mihira | Brahma-gupta | Lalla | |
| Citrā | Pearl | 1 | 1 | 1 | α Virginis (Spica) |
| Svātī | Coral bead | 1 | 1 | 1 | α Bootis (Arcturus) |
| Viśākhā | An arched doorway | 5 | 2 | 4 | ι, γ, β, α Librae |
| Anurādhā | Heaps of offering to gods | 4 | 4 | 4 | δ, β, π Scorpionis |
| Jyeṣṭhā | Ear-pendant | 3 | 3 | 3 | α, σ, τ Scorpionis |
| Mūla | Tail of a lion | 11 | 2 | 11 | λ, υ, κ, ι, θ, η, ζ, μ, ε Scorpionis |
| Pūrvā-ṣāḍha | Tusk of an elephant | 2 | 4 | 2 | δ, ε Sagittarii |
| Uttarā-ṣāḍha | *Mañca* | 3 | 4 | 2 | σ, ζ Sagittarii |
| Śravaṇa | Three feet | 3 | 3 | 3 | α, β, γ Aquilae |
| Dhaniṣṭhā | Drum | 5 | 5 | 4 | β, α, γ, δ Delphini |
| Śatabhiṣak | Circle | 100 | 1 | 100 | λ Aquarii, etc. |
| Pūrva-Bhādrapada | *Mañca* | 2 | 2 | 2 | α, β Pegasi |
| Uttara-Bhādrapada | Pair | 8 | 2 | 2 | γ Pegasi, α Andromedae |
| Revatī | Drum | 32 | 1 | 32 | ζ Piscium, etc. |

Positions of the junction-stars of the asterisms (*nakṣatras*) in the twelve signs, Aries, etc:

63-66(i). In Aries, eight, twenty-seven; in Taurus, six, nineteen; in Gemini, two, ten; in the next sign (i.e., Cancer), two, fifteen, twenty-four; in Leo, eight and a half, twenty-one; in Virgo, four, twenty-three; in Libra, five, seventeen; in the next sign (i.e., Scorpio), two, twelve, eighteen; in Sagittarius, one, fourteen, twenty-seven; in Capricorn, fifteen, twenty-six; in Aquarius, seven, twenty-eight ; in the last sign (i.e., Pisces), fifteen, thirty—these are the degrees of the positions (with reference to the signs) of the junction-stars of the *nakṣatras* beginning with Aśvinī.

The prominent stars of the *nakṣatras* which were used in the study of the conjunction of the planets, especially the Moon, with them are called junction-stars (*yoga-tārā*).[1] The study of the conjunction of the planets with the junction-stars was originally meant to verify the computed longitudes of the planets with a view to test the accuracy of and to make improvements, if necessary, in the astronomical theories on which those computations were based.

The longitudes of the junction-stars which have been enumerated in the text are, in some cases, slightly at variance with those given by the author in his subsequent smaller work, the *Laghu-Bhāskarīya*. The differences are exhibited by the following table:

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[1] "Of the stars in each *nakṣatra*, those that are seen to be the brightest are the junction-stars." *KK* (Sengupta's edition), x. 3(i). The author of the *Sūrya-siddhānta* gives the relative position of the junction-star in each *nakṣatra*, which facilitates their identification. See *SūSi*, viii. 16-21.

**Differences between the Longitudes of the Junction-Stars in the Two Works of Bhaskara I**

| Junction-star of | Longitude given in | | Difference |
|---|---|---|---|
| | *Mahā-Bhāskarīya* | *Laghu-Bhāskarīya* | |
| Aśvinī | 8° | 8° | |
| Bharaṇī | 27° | 26° 30′ | — 30′ |
| Kṛttikā | $1^{S}$ 6° | $1^{S}$ 6° | |
| Rohiṇī | $1^{S}$ 19° | $1^{S}$ 20° | + 1° |
| Mṛgaśirā | $2^{S}$ 2° | $2^{S}$ 2° | |
| Ārdrā | $2^{S}$ 10° | $2^{S}$ 10° | |
| Punarvasu | $3^{S}$ 2° | $3^{S}$ 2° | |
| Puṣya | $3^{S}$ 15° | $3^{S}$ 15° | |
| Āśleṣā | $3^{S}$ 24° | $3^{S}$ 24° | |
| Maghā | $4^{S}$ 8° 30′ | $4^{S}$ 8° 30′ | |
| Pūrvā Phlāgunī | $4^{S}$ 21° | $4^{S}$ 21° | |
| Uttarā Phālgunī | $5^{S}$ 4° | $5^{S}$ 4° | |
| Hasta | $5^{S}$ 23° | $5^{S}$ 23° | |
| Citrā | $6^{S}$ 5° | $6^{S}$ 5° | |
| Svātī | $6^{S}$ 17° | $6^{S}$ 17° | |
| Viśākhā | $7^{S}$ 2° | $7^{S}$ 2° | |
| Anurādhā | $7^{S}$ 12° | $7^{S}$ 12° | |
| Jyeṣṭhā | $7^{S}$ 18° | $7^{S}$ 18° | |
| Mūla | $8^{S}$ 1° | $8^{S}$ 1° 30′ | + 30′ |
| Pūrvāṣāḍha | $8^{S}$ 14° | $8^{S}$ 14° 30′ | + 30′ |
| Uttarāṣāḍha | $8^{S}$ 27° | $8^{S}$ 26° 30′ | — 30′ |

| Junction-star of | Longitude given in | | Difference |
|---|---|---|---|
| | *Mahā-Bhāskarīya* | *Laghu-Bhāskarīya* | |
| Śravaṇa | $9^S$ 15° | $9^S$ 14° 30′ | — 30′ |
| Dhaniṣṭhā | $9^S$ 26° | $9^S$ 25° 30′ | — 30′ |
| Śatabhiṣak | $10^S$ 7° | $10^S$ 7° | |
| Pūrva-Bhādrapada | $10^S$ 28° | $10^S$ 28° | |
| Uttara-Bhādrapada | $11^S$ 15° | $11^S$ 15° | |
| Revatī | $12^S$ | $12^S$ | |

The following table gives the longitudes of the junction-stars of the *nakṣatras* as stated in the *Mahā-Bhāskarīya*, the *Laghu-Bhāskarīya*, the *Śiṣya-dhī-vṛddhida*, the *Sūrya-siddhānta*, the *Siddhānta-śekhara*, and the *Siddhānta-śiromaṇi* :

**Longitudes of the Junction-Stars according to various Hindu Authorities**

| Junction-star of | Longitude according to | | | (Polar) longitude according to | |
|---|---|---|---|---|---|
| | *MBh* | *LBh* | *ŚiDVṛ* | *SūSi* | *BrSpSi, KK, SiŚe SiŚi* |
| Aśvinī | 8° | 8° | 8° | 8° | 8° |
| Bharaṇī | 27° | 26°30′ | 20° | 20° | 20° |
| Kṛttikā | 36° | 36° | 36° | 37°30′ | 37°28′ |
| Rohiṇī | 49° | 50° | 49° | 49°30′ | 49°28′ |
| Mṛgaśirā | 62° | 62° | 62° | 63° | 63° |
| Ārdrā | 70° | 70° | 70° | 67°20′ | 67° |
| Punarvasu | 92° | 92° | 92° | 93° | 93° |

| Junction-star of | Longitude according to | | | (Polar) longitude according to | |
|---|---|---|---|---|---|
| | *MBh* | *LBh* | *ŚiDVṛ* | *SūSi* | *BrSpSi, SiŚe, SiŚi* |
| Puṣya | 105° | 105° | 105° | 106° | 106° |
| Āśleṣā | 114° | 114° | 114° | 109° | 108° |
| Maghā | 128°30′ | 128°30′ | 128° | 129° | 129° |
| Pūrvā Phālgunī | 141° | 141° | 139°20′ | 144° | 147° |
| Uttarā Phālgunī | 154° | 154° | 154° | 155° | 155° |
| Hasta | 173° | 173° | 173° | 170° | 170° |
| Citrā | 185° | 185° | 184°20′ | 180° | 183° |
| Svātī | 197° | 197° | 197° | 199° | 199° |
| Viśākhā | 212° | 212° | 212° | 213° | 212°5′ |
| Anurādhā | 222° | 222° | 222° | 224° | 224°5′ |
| Jyeṣṭhā | 228° | 228° | 228° | 229° | 229°5′ |
| Mūla | 241° | 241°30′ | 241° | 241° | 241° |
| Pūrvāṣāḍha | 254° | 254°30′ | 254° | 254° | 254° |
| Uttarāṣāḍha | 267° | 266°30′ | 267°20′ | 260° | 260° |
| Śravaṇa | 285° | 284°30′ | 283°10′ | 280° | 278° |
| Dhaniṣṭhā | 296° | 295°30′ | 296°20′ | 290° | 290° |
| Śatabhiṣak | 307° | 307° | 313°20′ | 320° | 320° |
| Pūrva-Bhādra-pada | 328° | 328° | 327° | 326° | 326° |
| Uttara-Bhādra-pada | 345° | 345° | 335°20′ | 337° | 337° |
| Revatī | 360° | 360° | 359° | 359°50′ | 0 |

The longitudes given in the *Mahā-Bhāskarīya*, the *Laghu-Bhāskarīya*, and the *Śiṣya-dhī-vṛddhida* are the usual celestial longitudes, whereas those given in the *Sūrya-siddhānta*, the *Brāhma-sphuṭa-siddhānta*, the *Siddhānta-śekhara* and the *Siddhānta-śiromaṇi* are the polar longitudes.[1] This explains why there are significant differences between them, but, as should be expected, the celestial longitudes as also the polar longitudes exhibit general agreement amongst themselves. The minor differences that occur in a few cases are probably due to the errors of observation or to the different methods used.

Celestial latitudes of the junction-stars, definition of the conjunction of a planet with a star, and a rule for determining the distance between a planet and a star when they are in conjunction:

66(ii)-71(i). North, ten, twelve, five; south, five, ten, eleven; north, six, zero; south, seven, zero; north, twelve, thirteen; south, seven, two; north, thirty-seven; south, one and a half, three, four, eight plus one-third, seven, seven plus one-third; north, thirty, thirty-six; south, eighteen minutes; north, twenty-four, twenty-six, zero—these have been stated by the learned to be the degrees of the celestial latitudes of the junction-stars of the *nakṣatras* beginning with Aśvinī.

All planets having their longitudes equal to those of the junction-stars are seen in conjunction with them.

The distance between a planet and a star (when they are in conjunction) is determined from their celestial latitudes.[2]

The celestial latitudes of the junction-stars stated above are exhibited in the following table. We also give the celestial latitudes stated in the other important works on Hindu astronomy.

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[1] That is, the longitudes of those points where the secondaries to the equater passing through the junction-stars intersect the ecliptic.

[2] See *MBh*, vi. 54,

**Celestial Latitudes of the Junction-Stars according to various Hindu Authorities**

| Junction-star of | Latitude given in | | | (Polar) latitude given in | | |
|---|---|---|---|---|---|---|
| | *MBh* | *LBh* | *ŚiDVṛ* | *SūSi* | *BrSpSi, KK, SiŚe* | *SiŚi* |
| Aśvinī | 10° N | 10° N | 10° N | 10° N | 10° N | 10° N |
| Bharaṇī | 12° N | 12° N | 12° N | 12° N | 12° N | 12° N |
| Kṛttikā | 5° N | 5° N | 5° N | 5° N | 4°31′ N | 4°30′ N |
| Rohiṇī | 5° S | 5° S | 5° S | 5° S | 4°33′ S | 4°30′ S |
| Mṛgaśirā | 10° S | 10° S | 10° S | 10° S | 10° S | 10° S |
| Ārdrā | 11° S | 11° S | 11° S | 9° S | 11° S | 11° S |
| Punarvasu | 6° N | 6° N | 6° N | 6° N | 6° N | 6° N |
| Puṣya | 0 | 0 | 0 | 0 | 0 | 0 |
| Āśleṣā | 7° S | 7° S | 7° S | 7° S | 7° S | 7° S |
| Maghā | 0 | 0 | 0 | 0 | 0 | 0 |
| Pūrvā-Phālgunī | 12° N | 12° N | 12° N | 12° N | 12° N | 12° N |
| Uttarā-Phālgunī | 13° N | 13° N | 13° N | 13° N | 13° N | 13° N |
| Hasta | 7° S | 7° S | 8° S | 11° S | 11° S | 11° S |
| Citrā | 2° S | 2° S | 2° S | 2° S | 1°45′ S | 1°45′ S |
| Svātī | 37° N | 37° N | 37° N | 37° N | 37° N | 37° N |
| Viśākhā | 1°30′ S | 1°30′ S | 1°30′ S | 1°30′ S | 1°23′ S | 1°20′ S |
| Anurādhā | 3° S | 3° S | 3° S | 3° S | 1°44′ S | 1°45′ S |
| Jyeṣṭhā | 4° S | 4° S | 4° S | 4° S | 3°30′ S | 3°30′ S |
| Mūla | 8°20′ S | 8°30′ S | 8°30′ S | 9° S | 8°30′ S | 8°30′ S |
| Pūrvāṣāḍha | 7° S | 7° S | 5°20′ S | 5°30′ S | 5°20′ S | 5°20′ S |
| Uttarāṣāḍha | 7°20′ S | 7° S | 5° S | 5° S | 5° S | 5° S |

| Junction-star of | Latitude Given in | | | (Polar) latitude give in | | |
|---|---|---|---|---|---|---|
| | *MBh* | *LBh* | *ŚiDVṛ* | *SūSi* | *BrSpSi, KK, SiŚe* | *SiŚi* |
| Śravaṇa | 30° N | 30° N | 30° N | 30° N | 30° N | 30° N |
| Dhaniṣṭhā | 36° N | 36° N | 36° N | 36° N | 36° N | 36° N |
| Śatabhiṣak | 18′ S | 18′ S | 20′ S | 30′ S | 18′ S | 20′ S |
| Pūrva-Bhādra-pada | 24° N | 24° N | 24° N | 24° N | 24° N | 24° N |
| Uttara-Bhādra-pada | 26° N | 26° N | 26° N | 26° N | 26° N | 26° N |
| Revatī | 0 | 0 | 0 | 0 | 0 | 0 |

Celestial latitudes of the Moon when she occults some of the prominent stars of the zodiac:

71(ii)-75(i). It is stated that the Moon, moving towards the south of the ecliptic, obliterates (i.e., occults) the cart of Rohiṇī (i. e., the constellation of Hyades), when her latitude amounts to 60 minutes; the junction-star (of Rohiṇī) (i. e., Aldebaran), when her latitude amounts to 256 minutes; (the junction-star of) Citrā (i.e., Spica), when her latitude amounts to 95 minutes; (the junction-star of) Jyeṣṭhā (i.e., Antares), when her latitude amounts to 200 minutes; (the junction-star of) Anurādhā[1] when her latitude amounts to 150 minutes; (the junction-star of) Śatabhiṣak (i. e., λ Aquarii), when her latitude amounts to 24 minutes; (the junction-star of) Viśākhā[2], when

[1] According to H. T. Colebrooke and E. Burgess, it is δ Scorpii. According to Bentley, it is β Scorpii.

[2] According to Colebrooke, it is α or κ Librae; according to Whitney and Burgess, it is 24 Librae.

her latitude amounts to 88 minutes; and (the junction-star of) Revatī (i.e., ζ Piscium), when her latitude vanishes. When she moves towards the north (of the ecliptic), she occults the *nakṣatra* Kṛttikā (i.e., the Pleiades), when her latitude amounts to 160 minutes; and the central star of the *nakṣatra* Maghā, when she assumes the greatest northern latitude. These minutes (of the Moon's latitude) which have been stated (here) in connection with the occultation of a star by the planet (Moon) are based on actual observation made by means of the instrument (called) Yaṣṭi.[1]

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[1] The occultations of the stars of the *nakṣatras* are stated also in *SūSi*, viii. 13; *BrSpSi*, x. 11-12; *KK*, x. 15-16; *LBh*, viii. 11-16; *ŚiDVṛ*, *I*, xi. 11; *SiŚe*, xii. 8-9.

CHAPTER IV

# TRUE LONGITUDE OF A PLANET

Definition of the Sun's mean anomaly:

1. Having applied the correction for the (local) longitude to the mean longitude of the Sun, subtract (therefrom) the longitude of the Sun's apogee (*ucca*): the remainder is the Sun's (mean) anomaly. In that (anomaly), three signs form a quadrant.

That is to say,

Sun's mean anomaly = (mean longitude of the Sun) — (longitude of the Sun's apogee).

The Sun's apogee is the remotest point of the Sun's apparent orbit.

Beginning with the Sun's apogee, in Hindu astronomy, the *kakṣāvṛtta* (deferent or concentric) for the Sun is divided into four equal parts called anomalistic quadrants (*pada or pāda*) and twelve equal parts called anomalistic signs (*rāśi*). Thus there are three anomalistic signs in an anomalistic quadrant. The anomalistic signs are given the same names as the signs of the zodiac, viz., Aries (*meṣa*). Taurus (*vṛṣa*), Gemini (*mithuna*), etc. When the mean anomaly of the Sun is between $0^{\circ}$ and $180^{\circ}$, the Sun is said to be in the six signs (or in the half-orbit) beginning with the anomalistic sign Aries;[2] and when the mean anomaly of the Sun is between $90^{\circ}$ and $270^{\circ}$, the Sun is said to be in the six signs (or in the half-orbit) commencing with the anomalistic sign Cancer; and so on. The same is true also for the planets, Mars, etc.

A rule relating to the Rsine of the Sun's mean anomaly:

2. (Of the parts of the Sun's mean anomaly lying) in the odd quadrants, calculate the Rsine; and (of the parts lying) in the even quadrants, calculate the Rversed-sine. The method

[1] This rule occurs also in *SūSi*, ii. 29; *BrSpSi*, ii. 12(i); *ŚiDVṛ*, *I*, ii. 10; *SiŚe*, iii. 12; *SiŚi*, *I*, ii. 18-19(i).

[2] Or, that the mean anomaly is in the six signs (or in the half-orbit) beginning with the sign Aries.

for finding the Rsines (i.e., Rsines and Rversed-sines) is being told in detail (below).

For example, if the Sun's mean anomaly is 140°, calculate the Rsine of 90° and the Rversed-sine of 50°; if the Sun's mean anomaly is 240°, calculate the Rsine of 90°, the Rversed-sine of 90°, and the Rsine of 60°; and if the Sun's mean anomaly be 300°, calculate the Rsine of 90°, the Rversed-sine of 90°, again the Rsine of 90°, and the Rversed-sine of 30°.

The above passage shows that in the time of Bhāskara I one of the methods used for finding the Rsine of an arc (>90°) was to apply the following formulae:

$$\begin{aligned}
\text{Rsin } (90^\circ+\theta) &= \text{Rsin } 90^\circ - \text{Rversin } \theta. \\
\text{Rsin } (180^\circ+\theta) &= \text{Rsin } 90^\circ - \text{Rversin } 90^\circ - \text{Rsin } \theta \\
&= - \text{Rsin } \theta. \\
\text{Rsin } (270^\circ+\theta) &= \text{Rsin } 90^\circ - \text{Rversin } 90^\circ - \text{Rsin } 90^\circ \\
&\quad + \text{Rversin } \theta \\
&= - \text{Rsin } 90^\circ + \text{Rversin } \theta,
\end{aligned}$$

where $\theta < 90^\circ$.

A rule for finding the Rsine (or Rversed-sine) of an arc (<90°):

3-4(i). Reduce the arc to minutes and then divide by 225: the quotient denotes the number of (tabulated) Rsine-differences (or Rversed-sine-differences) to be taken completely. Then multiply the remainder by the next (or current) Rsine-difference (or Rversed-sine-difference) and divide (the product) by 225. Add the quotient (thus obtained) to the sum of the (tabulated) Rsine-differences (or Rversed-sine-differences) obtained before. The sum thus obtained is the Rsine (or Rversed-sine) of the given arc.[1]

This rule gives a method for calculating the Rsine or Rversed-sine of an arc by the help of the following table of Rsine-differences given by Āryabhaṭa I in his *Āryabhaṭīya*[2].

[1] This rule occurs also in *SūSi*, ii. 31-32; *BrSpSi*, ii. 10; *LBh*, ii. 2 (ii)-3(i); *ŚiDVṛ*, *I*, ii. 12; *SiŚe*, iii. 15; *SiŚi*, *I*, ii. 10(ii)-11.

[2] i. 12. This table has been referred to in *MBh*, vii. 13,

**Table of Rsine-differences**

| Serial No. | Rsine-difference in minutes | Serial No. | Rsine-difference in minutes | Serial No. | Rsine-difference in minutes | Serial No. | Rsine-difference in minutes |
|---|---|---|---|---|---|---|---|
| 1 | 225 | 7 | 205 | 13 | 154 | 19 | 79 |
| 2 | 224 | 8 | 199 | 14 | 143 | 20 | 65 |
| 3 | 222 | 9 | 191 | 15 | 131 | 21 | 51 |
| 4 | 219 | 10 | 183 | 16 | 119 | 22 | 37 |
| 5 | 215 | 11 | 174 | 17 | 106 | 23 | 22 |
| 6 | 210 | 12 | 164 | 18 | 93 | 24 | 7 |

This table gives the Rsine-differences corresponding to the twenty-four elementary arcs in which a quadrant of a circle is divided, each elementary arc being equal to 225 minutes. The same table reversed becomes the table of Rversed-sine-differences.

**Table of Rversed-sine-differences**

| Serial No. | Rversed-sine-difference in minutes | Serial No. | Rversed-sine-difference in minutes | Serial No. | Rversed-sine-difference in minutes | Serial No. | Rversed-sine-difference in minutes |
|---|---|---|---|---|---|---|---|
| 1 | 7 | 7 | 93 | 13 | 164 | 19 | 210 |
| 2 | 22 | 8 | 106 | 14 | 174 | 20 | 215 |
| 3 | 37 | 9 | 119 | 15 | 183 | 21 | 219 |
| 4 | 51 | 10 | 131 | 16 | 191 | 22 | 222 |
| 5 | 65 | 11 | 143 | 17 | 199 | 23 | 224 |
| 6 | 79 | 12 | 154 | 18 | 205 | 24 | 225 |

The method for calculating the Rsine or Rversed-sine of an arc, as stated in the text, may be explained by means of an example as follows:

Example. Calculate Rsin 32° and Rversin 32°.

Reducing 32 degrees to minutes, we get 1920′. Dividing this by 225, we get 8 as the quotient and 120 as the remainder.

(1) The sum of the first 8 Rsine-differences is 1719′. Multiplying the remainder 120 by the 9th Rsine-difference (viz. 191′) and dividing the product by 225, we get 101′ 52″. Adding this to the previous sum, we get 1820′ 52″ or 1821′ approx. This is the value of Rsin 32°.

(2) The sum of the first 8 Rversed-sine-differences is 460′. Multiplying the remainder 120 by the 9th Rversed-sine-difference (viz. 119′) and dividing that product by 225, we get 63′ 28″. Adding this to the previous sum, we get 523′ 28″ or 523′ approx. This is the value of Rversin 32°.[1]

The above method for finding the Rsine of a given arc is evidently based on the simplest law of interpolation, viz. that of proportion. In later works, we come across more elegant methods of interpolation. We state here two of them.

**1. Brahmagupta's formula.**

If $\theta < 225'$ and t be an integer, then

$$\text{Rsin}\,(225'\text{t}+\theta') = \text{sum of t Rsine-differences} + \frac{\theta'}{225}\left\{\frac{\text{t}^{\text{th}}\text{ Rsine-diff.} + (\text{t}+1)^{\text{th}}\text{ Rsine-diff.}}{2} - \frac{\theta'}{225}\cdot\frac{\text{t}^{\text{th}}\text{ Rsine-diff.} - (\text{t}+1)^{\text{th}}\text{ Rsine-diff.}}{2}\right\}. \quad (1)$$

$$= \text{sum of t Rsine-differences} + \frac{\theta'}{225}\{(\text{t}+1)^{\text{th}}\text{ Rsine-difference}\} + \frac{1}{2}\cdot\frac{\theta'}{225}\left(\frac{\theta'}{225}-1\right)\{(\text{t}+1)^{\text{th}}\text{ Rsine-difference} - \text{t}^{\text{th}}\text{ Rsine-difference}\}. \quad (2)$$

[1] Using modern four-figure tables and assuming that one radian = 206265″, we get Rsine 32° = 30° 21′ 43″ approx. and Rversin 32° = 8°42′ 22″ approx. This shows that the values derived from Āryabhaṭa I's table give fairly good approximations to the Rsines and Rversed-sines up to minutes of arc.

Form (1) occurs in P. C. Sengupta's edition of the *Khaṇḍakhādyaka*[1] of Brahmagupta and also in the *Siddhānta-śiromaṇi*[2] of Bhāskara II. Form (2) is found to occur in Parameśvara's commentary on the *Laghu-Bhāskarīya*[3]. This formula agrees with Newton's interpolation formula for equidistant knots.

**2. Madhava's formula.**

If t be a positive integer and $\theta < 225'$, then

Rsin $(225' t + \theta')$ = sum of t Rsine-differences

$$+\frac{\theta \times [\text{Rcos}\,\{225'(t+1)\} + \text{Rcos}\,(225't)]}{2R}.$$

This formula is ascribed to Mādhava by Nīlakaṇṭha in his commentary on the *Āryabhaṭīya*.[4] It occurs also in the *Tantra-saṅgraha*.[5]

In Chapter VII of the present work, Bhāskara I gives a very interesting method for finding the Rsine of a given arc without the use of a table.[6]

A rule for finding the Sun's equation of the centre:

4(ii). The Rsines and Rversed-sines (of the parts of the Sun's mean anomaly lying in the odd and even quadrants respectively) should be (severally) multiplied by the (Sun's) own epicycle and divided by 80: the resulting quantities should be subtracted and added (in the manner prescribed below).[7]

Application of the Sun's equation of the centre:

5. The resulting quantities due to the first, second, third and fourth anomalistic quadrants should always be respectively subtracted from, added to, added to, and subtracted from the Sun's mean longitude corrected for the (local) longitude.[8]

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[1] ix. 8.

[2] *I*, ii, 16.

[3] ii. 2(ii)-3(i).

[4] ii. 12.

[5] ii. 10-13(i).

[6] See *infra* chapter VII, stanzas 17-19.

[7] This correction is found also in *BrSpSi*,i i. 15(ii) and *SiŚe*, iii, 27.

[8] This correction is found also in *BrSpSi*, ii. 16(i). Also see *SiŚe*, iii. 28(i).

Alternative rule for the determination and application of the Sun's equation of the centre (called *bāhuphala*):

6. Or, (find the *bāhuphala* and) subtract the *bāhuphala* when the (Sun's mean) anomaly is in the half-orbit beginning with Aries; and add that when (the Sun's mean anomaly is) in the half-orbit beginning with Libra. This correction should always be performed by one who seeks the true longitude (of the Sun).[1]

*Bāhu* ( due to a planet's mean anomaly) is defined in stanza 8 below. It is the arcual distance of a planet from its apogee or perigee, whichever is nearer. The Sun's *bāhuphala* is obtained by the following formula:

$$\text{Sun's } b\bar{a}huphala = \frac{(\text{Sun's tabulated epicycle}) \times \text{Rsin } (b\bar{a}hu \text{ due to the Sun's mean anomaly})}{80}$$

The Sun's tabulated epicycle is 3.[2]

The Sun's *bāhuphala* corresponds to the Sun's equation of the centre, which is shown by means of the Hindu epicyclic theory as follows:

In the adjoining figure, the bigger circle UMN, centred at the Earth E, is the Sun's mean orbit called *kakṣāvṛtta* (deferent); the small circles are *nicoccavṛttas* (epicycles); and U is the Sun's *ucca* (apogee).

Under the epicyclic theory, the mean Sun is supposed to move on the deferent, and the true Sun is supposed to move on its epicycle (centred at the mean planet) with the same angular velocity as the mean Sun has relative to the apogee but in the opposite sense. (See the arrows).

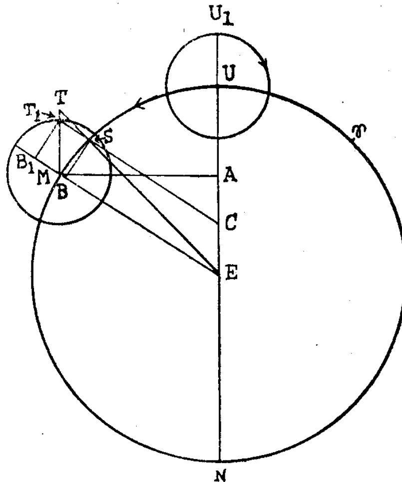


Fig. 11

[1] This rule is found to occur also in *SūSi*, ii. 39; *ŚiDVṛ*, *I*, ii. 14; *SiŚe*, iii. 26(i).

[2] *Vide infra*, vii. 16. It must be noted that the epicycles have been tabulated after abrading them by 4½.

Initially, when the mean Sun is at U, the true Sun is at $U_1$. Subsequently, when the mean Sun is at M, the true Sun is at $T_1$, such that $MT_1$ is parallel to EU. Since both the mean Sun and the true Sun have the same angular velocity relative to the apogee, the line $MT_1$ will always be parallel to EU.

According to the Hindu astronomers, the tabulated (*manda*) epicycles are the mean epicycles (i.e., the epicycles corresponding to the mean distances of the planets) whereas the true epicycles (on which the planets are supposed to move) are those which correspond to their true distances.[1] That is to say, the point $T_1$ in the above figure is not the position of the true Sun.

*According to the Hindu theory* the true epicycle and the true position of the Sun, when the mean Sun is at M, are obtained as follows:

Let C be a point in EU such that $EC=UU_1$. Join $CT_1$ and let it intersect the deferent at S. Produce ES and $MT_1$ to meet at T. Then MT is the radius of the true epicycle at M and T the true position of the Sun. Obviously, the epicycle varies from point to point.

If ♈ denote the first point of Aries. Then

Sun's mean longitude = arc ♈UM,

and Sun's true longitude=arc ♈US.

The difference between the two, i.e., arc SM, is the Sun's equation of the centre.

Let MA be perpendicular to EU and $T_1B_1$ and SB be perpendiculars to EM or EM produced. $T_1B_1$ is called *bāhuphala* or *bhujāphala* and $B_1M$ is called *koṭiphala*.

The triangles $B_1MT_1$ and MAE are similar. Therefore,

$$\frac{T_1B_1}{T_1M}=\frac{MA}{EM},$$

or, $T_1B_1$, i.e., Sun's *bāhuphala* $=\dfrac{T_1M\times MA}{EM}$

$$=\frac{(\text{ radius of Sun's mean epicycle })\times \text{Rsin (arc MU)}}{R}$$

$$=\frac{\text{(Sun's tabulated epicycle)}\times \text{Rsin (}\textit{bāhu}\text{ due to the Sun's mean anomaly)}}{80}.$$

[1] See *BrSpSi*, xxi. 29; *SiŚe*, xvi. 24; *SiŚi, II*, v. 36-37. Also see Bhāskara II's comm. on *SiŚi, II*, v. 36-37; and the extract from the *Ādityapratāpa-siddhānta* quoted by Āmarāja in his comm. on *KK*, page 33.

But $T_1B_1$=SB=arc SM approx.

Hence it follows that the Sun's *bāhuphala* is the same as the Sun's equation of the centre.

If $\theta$ denote the *bāhu* due to the Sun's mean anomaly, then according to Āryabhaṭa I and Bhāskara I

$$\text{Sun's } bāhuphala=\frac{3\times \text{Rsin }\theta}{80}$$

$$=\frac{3\times 3438'\times \sin\,\theta}{80}$$

$$=128'{\cdot}9 \sin\,\theta$$

$$={\cdot}0375 \sin\,\theta \text{ radians.} \qquad (1)$$

According to Ptolemy, the greatest equation of the centre for the Sun = $2^{\circ}\,23'$. Therefore, according to him,

$$\text{Sun's equation of the centre} = 2^{\circ}23'\sin\theta$$

$$= 143'\ \sin\,\theta$$

$$=\frac{143\ \sin\,\theta}{3438}\ \text{radians}$$

$$= {\cdot}0416 \sin\,\theta \text{ radians.} \qquad (2)$$

According to modern astronomy,

$$\text{Sun's equation of the centre} = 2e \sin\,\theta\text{, where } e= {\cdot}0167$$

$$= {\cdot}0334\ \sin\,\theta, \qquad (3)$$

neglecting $e^2$ and higher powers of $e$.

Comparison of the results (1), (2), and (3) shows that the Hindu approximation for the Sun's equation of the centre in good enough and much better than that of Ptolemy.

**Addition and subtraction of the *bāhuphala*.**

When the Sun's mean anomaly is less than 180°, the true Sun is behind the mean Sun; and when the Sun's mean anomaly is greater than 180°, the true Sun is in advance of the mean Sun. Hence the Sun's *bāhuphala* is subtractive or additive according as the Sun's mean anomaly is in the half-orbit beginning with Aries or in the half-orbit beginning with Libra.

The Sun's *bāhuphala* correction is applied to the Sun's mean longitude as corrected for the longitude-correction (i.e., to the Sun's mean longitude for mean sunrise at the *svanirakṣa* place). And after the *bāhuphala* correction has been made, we obtain the Sun's true longitude for mean sunrise at the *svanirakṣa* place.

Sun's correction for the equation of time due to the eccentricity of the ecliptic (called *bhujāntara* or *bhujāvivara* correction):

7. Multiply the mean daily motion (of the Sun) by the (Sun's) equation (of the centre derived from the Rsines and Rversed-sines of the parts of the Sun's mean anomaly lying in the odd ond even quadrants respectively)[1] or by the (Sun's) *bāhuphala* (i.e., the Sun's equation of the centre derived from the *bāhu*) and then divide the product by the number af minutes in a circle (i.e., by 21600); apply that (as correction, positive or negative, to the Sun's mean longitude corrected for the local longitude and for the Sun's equation of the centre) as before.[2]

The *bhujāntara* correction is the third correction to be applied to the Sun's mean longitude. By this correction "allowance is made for that part of the equation of time, or of the difference between mean and apparent solar time, which is due to the difference between the Sun's mean and true places".[3] This correction having been applied to the Sun's longitude, we obtain the Sun's true longitude for true sunrise at the *svanirakṣa* place.

In the case of the Moon and other planets, according to the commentator Parameśvara[4], this correction is applied to the mean longitude as corrected for the longitude-correction.

The *bhujāntara* correction is subtractive when the Sun's mean anomaly is less than 180° and additive when the Sun's mean anomaly is greater than 180°, because in the former case true sunrise occurs earlier than mean sunrise and in the latter case true sunrise occurs later than mean sunrise.

The correction for "the equation of time due to the obliquity of the ecliptic" occurs for the first time in the *Siddhānta-śekhara* of Śrīpati (c.1039

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[1] *Vide supra* stanza 4(ii).

[2] *Vide* stanzas 5 and 6. This rule occurs also in *SūSi*, ii. 46; *BrSpSi*, ii. 29(i); *ŚiDVṛ*, *I*, ii. 16.

[3] E. Burgess, *English Translation of the Sūrya-siddhānta*, Calcutta (1935), page 87.

[4] *Vide* his comm. on *MBh*, iv. 29-30.

A. D.) under the name of *udayāntara-saṁskāra.*[1] It reappears in the works of Bhāskara II[2] (1150 A. D.) and Nīlakaṇṭha[3] (1500 A. D.).

Definitions of the *bāhu* and *koṭi* (due to a planet's **mean** anomaly):

8. The portions (of the mean anomalistic quadrant) traversed and to be traversed (by a planet) are called *bāhu* and *koṭi* or *koṭi* and *bāhu*, according as the mean anomalistic quadrant (occupied by the planet) is odd or even.[4] The *bāhuphala* and *koṭiphala* are obtained as before for the determination of the hypotenuse (i.e., the distance of the planet).

A rule for the determination of the true distance in minutes of the Sun or Moon:

9-12. (When the Sun or Moon is) in the first or fourth (mean anomalistic) quadrant, add the *koṭiphala* to the radius; (when) in the remaining (quadrants), subtract that from the radius: the resulting sum or difference is the upright. The square root of the sum of the squares of that and the *bāhuphala* is called the hypotenuse. Multiply that hypotenuse (severally) by the *bāhuphala* and *koṭiphala* and divide (each product) by the radius: the results are (again) the *bāhuphala* and *koṭiphala*. From them obtain the hypotenuse (again) as before. Again multiply this hypotenuse (severally) by the initial *bāhuphala* and *koṭiphala* and divide (each product) by the radius. In this way, proceeding as above, obtain the hypotenuse again and again until two successive values of the hypotenuse agree (to minutes). (Thus is obtained the nearest approximation to the true distance in minutes of the Sun or Moon).[5]

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[1] *SiŚe*, xi. 1,

[2] *SiŚi, I*, ii. 62-63.

[3] *TS*, ii. 30.

[4] This definition is found also in *SūSi*, ii. 30; *BrSpSi*, ii. 12(ii); *ŚiDVṛ, I*, ii. 10-11; *SiŚe*, iii. 13(i); *SiŚi, I*, ii. 19.

[5] *Cf. LBh*, ii. 6-7.

Fig. 12 is a reproduction of the previous figure. As in the previous figure, M is the mean Sun and T the true Sun. ET is the true distance of the Sun. The above rule relates to the determination of ET. The method used is the method of successive approximations.

In the triangle ESD, where SD is parallel to EU, we have

$$ES = R,$$

and $SD = T_1M$, the radius of the Sun's mean epicycle. If the value of TM, the radius of the Sun's true epicycle, were known, the Sun's true distance ET could be easily derived from a comparison of the similar triangles ESD and ETM. But the value of TM is unknown and is itself dependent on that of ET. Hence the necessity of the method of successive approximations (*asakṛtkarma*).

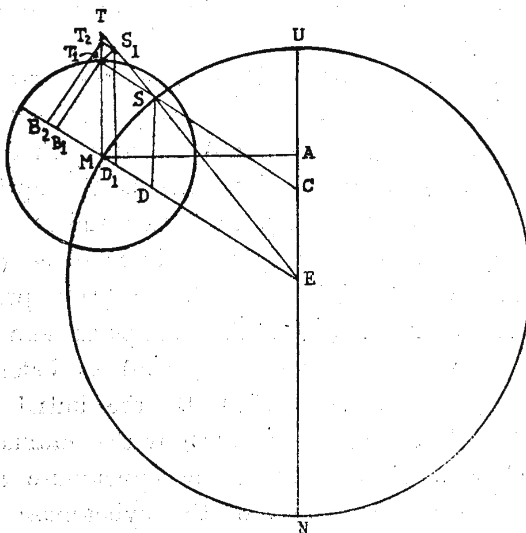



Fig. 12

With centre E and radius $ET_1$ draw an arc of a circle cutting ET at $S_1$; through $S_1$ draw a line $S_1D_1$ parallel to EU and a line $S_1T_2$ parallel to EM meeting $MT_1$ produced at $T_2$; and from $T_2$ draw a line $T_2B_2$ perpendicular to EM produced. Again with centre E and radius $ET_2$ draw an arc of a circle cutting ET at $S_2$; through $S_2$ draw a line $S_2D_2$ parallel to EU and a line $S_2T_3$ parallel to EM meeting $MT_1$ produced at $T_3$; and from $T_3$ draw a line $T_3B_3$ perpendicular to EM produced. Continue this process successively. The sequence of points $S_1$, $S_2$, $S_3$,...and also that of points $T_1$, $T_2$,

$T_3$,...will converge to T. This is the basis of the method used. The details are as follows:

$MT_1$ is taken as the first approximation $r_1$ to the radius of the Sun's true epicycle and likewise $ES_1$, which is equal to[1]

$$\sqrt{(R+\textit{koṭiphala})^2+(\textit{bāhuphala})^2},$$

is taken as the first approximation $H_1$ to the Sun's true distance.[2]

Now from the similar triangles $S_1D_1E$ and SDE,

$$S_1D_1 = \frac{SD \times H_1}{R} = \frac{r_1 \times H_1}{R}.$$

But $MT_2=S_1D_1$. Therefore,

$$MT_2=\frac{r_1 \times H_1}{R}. \qquad (1)$$

Again from the similar triangles $T_2B_2M$ and MAE, we have

$$T_2B_2=\frac{MA \times T_2M}{R}$$

$$=\frac{MA \times r_1}{R} \cdot \frac{H_1}{R}$$

$$=\frac{\textit{bāhuphala} \times H_1}{R}. \qquad (2)$$

$$\text{Similarly, } B_2M = \frac{\textit{koṭiphala} \times H_1}{R}. \qquad (3)$$

Therefore,

$$ET_2=\sqrt{(R+MB_2)^2+T_2B_2^2},$$

where $MB_2$ and $T_2B_2$ are given by (3) and (2) respectively.

$MT_2$ is taken as the second approximation $r_2$ to the radius of the Sun's true epicycle and likewise $ES_2$ ( $=ET_2$ ) is taken as the second approximation $H_2$ to the Sun's true distance.

Since $H_1 > R$, therefore from (1)

$$r_2 > r_1;$$

and consequently,

$$H_2 > H_1.$$

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[1] For, $ES_1=ET_1$; and from the right-angled triangle $T_1B_1E$, we have

$$ET_1^2=EB_1^2+B_1T_1^2=(EM+MB_1)^2+B_1T_1^2,$$

where $EM=R$, $MB_1$ is the *koṭiphala* and $B_1T_1$ is the *bāhuphala*.

[2] In the right-angled triangle $EB_1T_1$, $B_1T_1$ is called the base, $EB_1$ is called the upright, and $ET_1$ is called the hypotenuse.

Similarly, $MT_3$, $MT_4$, ... are the next successive approximations $r_3$, $r_4$, ... to the radius of the Sun's true epicycle, and $ET_3$, $ET_4$, ... are the next successive approximations $H_3$, $H_4$, ... to the Sun's true distance. As before, it can be easily shown that

$$r_n < r_{n+1}$$

$$\text{and} \quad H_n < H_{n+1}.$$

Moreover, from the method of construction $r_1$, $r_2$, $r_3$, ... are each less than MT, which is the upper bound of the sequence $\{r_n\}$, and $H_1$, $H_2$, $H_3$, ... are each less than ET, which is the upper bound of the sequence $\{H_n\}$.

Hence it follows that

$$r_1 < r_2 < r_3 < \dots < r_n < \dots < MT.$$

and $$H_1 < H_2 < H_3 < \dots < H_n < \dots < ET.$$

The sequen ces $\{r_n\}$ and $\{H_n\}$ are each monotonic and therefore convergent. The first converges to MT, the radius of the Sun's true epicycle, and the second to ET, the Sun's true distance.

It may be seen that the sequences $\{r_n\}$ and $\{H_n\}$ converge rapidly so that the third or fourth approximation will give the result correct to the minute. In actual practice, however, the process of successive approximations is carried on until two successive approximations are the same to minutes of arc. For this reason. this process is sometimes called *aviśeṣakarma* ("the process of reducing the difference to zero").[1]

The method explained above is applicable to the Sun as also to the Moon.

If in the above figure DM (which is equal to $ST_1$) be assumed to be equal to $SS_1$, i. e., $H_1 - R$, we shall have

$$ED = R - (H_1 - R)$$
$$= 2R - H_1,$$

and likewise, from the similar triangles SDE and TME, we shall get

$$ET = \frac{ES \times EM}{ED},$$

$$= \frac{R^2}{2R - H_1},$$

[1] In the above discussion, we have assumed the Sun to be in the first anomalistic quadrant as shown in the figure. When the Sun is in any other quadrant. the procedure is similar.

which is Bhāskara II's approximation for the true distance of the Sun or Moon.[1]

It may be pointed out here that the method of successive approximations, which has been used for finding the true distance of the Sun or Moon in the stanzas under consideration, was used by Lalla for determining the radii of the true epicycles of the Sun and Moon.[2]

A rule for finding the true daily motion (called *karṇabhukti*) of the Sun or Moon:

13. Always multiply the (mean) daily motion of the Sun or Moon by the radius and (then) divide (the product) by the hypotenuse (i.e., the true distance) determined by the method of successive approximations; the result is the true daily motion (of the Sun or Moon).

That is

$$\text{Sun's true daily motion} = \frac{\text{Sun's mean daily motion} \times R}{\text{Sun's true distance in minutes}},$$

$$\text{and Moon's true daily motion} = \frac{\text{Moon's mean daily motion} \times R}{\text{Moon's true distance in minutes}},$$

where R is the standard radius (=3438′).[3]

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[1] See *SiŚi, I*, v. 4.

[2] See *ŚiDVṛ, I*, ii. 44.

[3] The object here is to obtain the angular velocity expressed in minutes, which will correspond also to the linear velocity in a circle of radius R. Parameśvara in his comm. on *LBh*, ii. 8 writes that, in place of the true distance in the above formulae, certain astronomers make use of the expression

$$R \mp \textit{koṭiphala} \mp \frac{(\textit{koṭiphala})^2}{R}, \qquad (1)$$

where — or + sign is taken according as the planet is in the half-orbit beginning with the anomalistic sign Cancer or in that beginning with the anomalistic sign Capricorn. It may be pointed out that the expression (1) is an approximate value of $H_2$, the second approximation to the true distance.

The true daily motion determined from the above formulae is called *karṇabhukti* ("the motion derived from the hypotenuse").

A rule for finding the true daily motion (called *jīvābhukti*) of the Sun:

14. Or, multiply the current Rsine-difference by the (mean) daily motion (of the Sun) and divide by 225. Then multiply that by the (Sun's) own (tabulated) epicycle and divide by 80: the result thus obtained subtracted from or added to the (Sun's) mean daily motion (according as the Sun is in the half-orbit beginning with the anomalistic sign Capricorn or in that beginning with the anomalistic sign Cancer) gives the true daily motion (of the Sun).[1]

Let $M$ and $M'$ be the mean longitudes and $S$ and $S'$ the true longitudes of the Sun at sunrise yesterday and today respectively. Also let $\theta$ and $\theta'$ be the corresponding values of the *bāhu* ( due to the Sun's mean anomaly).[2] Then, we have

$$S=M\mp\frac{\text{Rsin }\theta\times r_1}{80}$$

and

$$S'=M'\mp\frac{\text{Rsin }\theta'\times r_1}{80},$$

where $r_1$ is the Sun's tabulated epicycle, $-$ or $+$ sign being taken according as the Sun's mean anomaly is less than 180° or greater.

Therefore,

$$S'-S=(M'-M)\mp\frac{(\text{Rsin }\theta'\backsim\text{Rsin }\theta)\times r_1}{80}$$

$$=m\mp\frac{(\text{Rsin }\theta'\backsim\text{Rsin }\theta)\times r_1}{80},$$

where $m$ denotes the Sun's mean daily motion, $-$ or $+$ sign being taken according as the Sun's mean anomaly is in the half-orbit beginning with the sign Capricorn or in that beginning with Cancer.

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[1] This rule occurs also in *ŚiDVṛ*, *I*, ii. 38 and *SiŚe*, iii. 40-41.

[2] *Vide supra*, stanza 8.

Neglecting the motion of the Sun's apogee and assuming that the Rsines vary uniformly,[1] we have

$$\text{Rsin }\theta' \backsim \text{Rsin }\theta = \frac{(\text{current Rsine-difference})\times m}{225} \text{ approx.}$$

Therefore,

$$S' - S = m \mp \frac{(\text{current Rsine-difference})\times m \times r_1}{225\times 80} \text{ approx.}$$

Hence the above rule.

Since the Sun's true daily motion has been obtained here with the help of the Rsines (*jīvā*), therefore it is generally called *jīvābhukti*.

A rule for finding the true daily motion (called *jīvābhukti*) of the Moon:

15-17. (When the Moon is in the odd quadrant) subtract the part of the *bāhu* due to her mean anomaly lying in the elementary arc corresponding to the current Rsine-difference (*antyajīvādhanuṣ-khaṇḍa*) from the daily motion of the (Moon's) mean anomaly; (when the Moon is) in the even quadrant, subtract the remainder obtained by subtracting that (part) from 225. Then take (as many) Rsine-differences in the reverse order, (if the Moon is) in the odd quadrant, or in the serial order, if the Moon is in the even quadrant, as correspond to (the above residue of) the motion of the (Moon's) mean anomaly (literally, the mean daily motion of the moon diminished by that of its apogee). (To the sum of those Rsine-differences) add the Rsine-differences (*phala*) corresponding to the arcs (of the daily motion of the Moon's mean anomaly which lie) in the first and last elementary arcs which are to be determined by proportion with the Rsine-differences (corresponding to those elementary arcs). Then calculate the (Moon's) equation of the centre (*phala*) corresponding to that (i.e., multiply that by the Moon's tabulated epicycle and divide by 80). The (Moon's) mean daily motion, when diminished or increased by that equation (according as the

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[1] The assumption that the Rsines vary uniformly is false.

Moon is in the half-orbit beginning with the anomalistic sign Capricorn or in that beginning with the anomalistic sign Cancer), becomes truer than the true.

The *rationale* of this rule is exactly similar to that of the previous rule. The difference is that the motion of the Moon's apogee is also taken into account in this case.

For a criticism of the *jīvābhukti*, see *LBh*, ii. 14-15(i).

Another rule for finding the motion of the Sun or Moon for the day elapsed or for the day to elapse:

18. The difference between the longitudes (of the Sun or Moon) computed for (sunrise) today and for (sunrise) yesterday is the motion (of the Sun or Moon) which has taken place (on the day elapsed).[1] The difference between the longitudes (of the Sun or Moon) computed for (sunrise) tomorrow and for (sunrise) today is stated to be the motion (of the Sun or Moon) which will take place (today).

A rule for determining the true distance in minutes of the Sun or Moon on the basis of the eccentric (*pratimaṇḍala*) theory:

19-20. Subtract (the Rsine of) the greatest equation of the centre from or add that to (the Rsine of) the *koṭi* (due to mean anomaly) depending on the anomalistic quadrant (i.e., according as the Sun or Moon is in the second and third or first and fourth anomalistic quadrants). The square root of the sum of the squares of that and (the Rsine of) the *bāhu* (due to mean anomaly) is the hypotenuse.[2] By that hypotenuse multiply (the Rsine of) the greatest equation of the centre, and then divide (the product) by the radius: add this result to or subtract that from the previous (Rsine of the) *koṭi* (as before). Continue this process until two successive approximations for the hypotenuse are the same (up to minutes). (Thus is obtained the true distance of the Sun or Moon).

[1] This rule occurs also in *SiŚi*, *I*, ii. 36(ii).

The author takes up now the Hindu eccentric theory. Here the mean Sun (or Moon) is supposed to move on a circle centred at the earth called the concentric (*kakṣāvṛtta*), whereas the true Sun (or Moon) is supposed to move on another equal circle called the eccentric (*pratimaṇḍala*) with the same angular velocity as the mean Sun (or Moon) has. The centre of the eccentric is supposed to be deviated from the Earth towards the Sun's (or Moon's) apogee by an amount equal to the Rsine of the Sun's (or Moon's) greatest equation of the centre.

In Fig. 13, the circle UMNY centred at E, the Earth, is the concentric and the circle $U_1T_1L$ centred at C is the eccentric for the Sun. When the mean Sun is at U, the true Sun is at $U_1$(the apogee). Subsequently, when the mean Sun is at M, the true Sun is at $T_1$. Since the mean Sun and the true Sun have the same angular velocity relative to the apogee, the line $MT_1$ will always be parallel to the apse line EU.

Let XY be perpendicular to EU through E, and $T_1B$ perpendicular to XY. Then in the triangle $T_1BE$, right-angled at B, we have

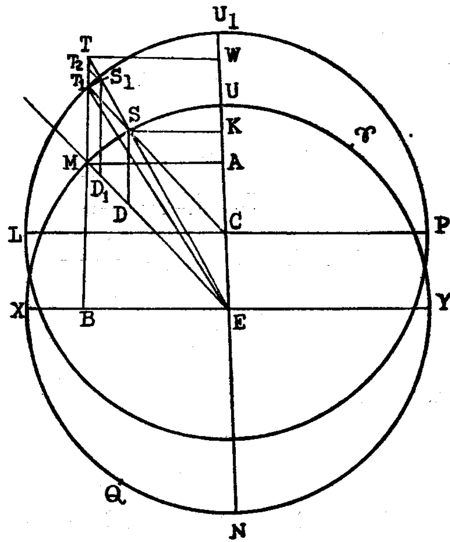



Fig.13 .

BE=MA=Rsin (arc MU),

and $T_1B = T_1M + MB = EC +$ Rsin (arc MX),

where the arc MX is the *koṭi* and EC is the Rsine of the greatest equation of the centre for the Sun.

Had the length EC been cqual to the radius of the Sun's true epicycle for the mean sun at M,$T_1E$ would have been the Sun's true distance, but EC corresponds to the radius of the Sun's tabulated epicycle, which is mean and not true, therefore $T_1$ is not the true position of the Sun and likewise $T_1E$ is not the true distance of the Sun. The true distance is determined as follows:

Join $T_1C$ and let it intersect thc concentric at S. Produce $MT_1$ and ES to meet at T. Then MT denotes the true distance between the centres of the concentric and the eccentric, T the position of the true Sun, and ET the true distance of the sun.

The method stated in the text relates to the determination of ET. It is based on the process of successive approximations and may be explained as follows:

With centre E and radius $ET_1$ draw an arc of a circle cutting ET at the point $S_1$, and through $S_1$ draw a line parallel to EM meeting MT at $T_2$. Again with centre E and radius $ET_2$ draw an arc of a circle cutting ET at $S_2$, and through $S_2$ draw a line parallel to EM to meet MT at $T_3$. Continue this process repeatedly. Also let SD, $S_1D_1$, $S_2D_2$,... be parallel to EU.

The method begins with assuming $MT_1$ as the first approximation $r_1$ to MT and likewise $ET_1$ is taken as the first approximation $H_1$ to ET.

Now from the similar triangles $S_1D_1E$ and SDE, we have

$$S_1D_1 = \frac{SD \times ES_1}{R} = \frac{r_1 \times H_1}{R}.$$

But $S_1D_1 = MT_2$.

Therefore, $$MT_2 = \frac{r_1 \times H_1}{R}. \quad (1)$$

Therefore, from the triangle $T_2BE$, right-angled at B, we have

$$ET_2 = \sqrt{(MB+MT_2)^2+BE^2},$$

where $MT_2$ is given by (1),

$MT_2$ is taken as the second approximation $r_2$ to MT, and $ET_2$ as the second approximation $H_2$ to ET.

Since $H_1 > R$, therefore $r_2 > r_1$; and consequently, $H_2 > H_1$.

Similarly, $MT_3$, $MT_4$, ... are the next successive approximations $r_3$, $r_4$, ... to MT, and $ET_3$, $ET_4$, ... are the next successive approximations $H_3$, $H_4$, ... to ET. Obviously,

$$r_n < r_{n+1} \text{ and } H_n < H_{n+1}.$$

Moreover, from the construction it is clear that $r_1$, $r_2$, $r_3$, ... are each less than MT, which is the upper bound of the sequence $\{r_n\}$; and $H_1$, $H_2$, $H_3$, ... are each less than ET, which is the upper bound of the sequence $\{H_n\}$.

Hence it follows that

$$r_1 < r_2 < r_3 < \dots < r_n < \dots < MT$$

and $$H_1 < H_2 < H_3 < \dots < H_n < \dots < ET.$$

Obviously, the sequences $\{r_n\}$ and $\{H_n\}$ are convergent. The former converges to MT and the latter to ET.

It will be noticed that the convergence is rapid, so that the third or fourth approximation will give the required distance correct to the minute. In practice, the process is repeated until two successive approximations agree to minutes.[1]

The process of finding the true distance of the Moon is similar.

It may be added that the position and distance of the Sun or Moon derived from the eccentric theory are the same as derived from the epicyclic theory.

A rule for the determination of the Sun's true longitude (for mean sunrise at the *svanirakṣa* place) under the eccentric theory:

21-23. Multiply the radius by the Rsine of the *bhuja* (due to the Sun's mean anomaly) and divide (the product) by the (Sun's true) distance. Add the arc corresponding to that (result) to the longitude of the (Sun's) own apogee depending on the anomalistic quadrant (occupied by the Sun) (as follows):

(When the Sun is in the first anomalistic quadrant, add) that arc itself, (when the Sun is in the second anomalistic quadrant, add) half a circle (i.e., 180°) as diminished by that arc, (when the Sun is in the third anomalistic quadrant, add) half a circle as increased by that arc, and (when the Sun is in the fourth anomalistic quadrant, add) a circle as diminished by that arc: the result is the true longitude of the Sun (for mean sunrise at the place where the local meridian intersects the equator).[2]

This is stated to be the determination (of the Sun's true longitude) under the eccentric theory. The greatest equation

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[1] In the above discussion we have assumed that the Sun is in the first anomalistic quadrant as shown in the figure. When the Sun is in the other quadrants, the process is similar.

[2] This rule occurs also in *BrSpSi*, xiv. 17-18 and *SiŚe*, iii. 52.

of the centre for each individual planet determines its own eccentric (*pratimaṇḍala*).

In Fig. 13, SK and TW are perpendiculars to the apse line EU. TW (which is equal to MA) is the Rsine of the *bhuja* (or *bāhu*) MU, and SK is the Rsine of the true *bhuja* (called *spaṣṭa-bhuja*) SU.

Comparing the similar triangles SKE and TWE, we have

$$\frac{SK}{SE} = \frac{TW}{TE},$$

$$\text{giving} \quad SK = \frac{TW \times SE}{TE},$$

$$\text{or Rsin (arc SU)} = \frac{\text{Rsin } (bhuja) \times R}{\text{Sun's true distance}}.$$

Therefore,

$$\text{arc SU} = \text{Rsin}^{-1} \left[\frac{\text{Rsin } (bhuja) \times R}{\text{Sun's true distance}}\right]. \qquad (1)$$

Now let ♈ be the first point of Aries. (See Fig. 13). Then, if the Sun is in the first anomalistic quadrant (as in the figure),

Sun's true longitude = arc ♈S = arc ♈U + arc SU.

= longitude of the Sun's apogee + arc SU.

When the Sun (i.e., the true Sun) is in the second quadrant, say at Q, the expression on the right hand side of (1) turns out to be the value of arc QN. Hence, in this case.

Sun's true longitude = arc ♈Q = arc ♈U + (180° — arc QN).

Similarly, in the remaining quadrants.

The method for finding the Moon's true longitude is similar.

A rule for finding the Sun's *bhujāntara* correction under the eccentric theory:

24. The (mean) daily motion (of the Sun) multiplied by the difference between the (Sun's) true and mean longitudes computed for the local place[1] and (the product then) divided by the number of minutes in a circle (i.e., by 21600) gives, as before, the (Sun's) *bhujāntara*.[2]

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[1] What is meant here is the *svanirakṣa* place, i.e., the place where the local meridian intersects the equator.

[2] This rule occurs also in *BrSpSi*, xiv. 19.

The *bhujāntara* correction is, as stated before, the correction for the equation of time due to the eccentricity of the ecliptic.

An approximate formula for finding the Rsine of the Sun's declination:

25. The Rsine of the Sun's longitude corrected for the three corrections (viz. *deśāntara*, *bāhuphala*, and *bhujāntara*), as multiplied by 13 and divided by 32, is (the Rsine of) the Sun's declination. The remaining determinations (such as the calculation of the day-radius, etc.) should be made as before.

From iii. 6-7, we have

$$\text{Rsin } \delta = \frac{1397 \times \text{Rsin } \lambda}{3438}, \tag{1}$$

where $\lambda$ and $\delta$ are the Sun's *sāyana* longitude and declination respectively.

Now

$$\frac{1397}{3438} = \frac{1}{2+} \frac{1}{2+} \frac{1}{5+} \frac{1}{1+} \frac{1}{9+} \frac{1}{1+} \frac{1}{9},$$

giving $\frac{1}{2}$, $\frac{2}{5}$, $\frac{11}{27}$, $\frac{13}{32}$, as the successive approximations of $\frac{1397}{3438}$.

Writing for $\frac{1397}{3438}$ its fourth approximation $\frac{13}{32}$, (1) reduces to

$$\text{Rsin } \delta = \frac{13 \times \text{Rsin } \lambda}{32},$$

which is the formula stated in the text.

A rule relating to the determination and application of the correction due to the ascensional difference of the Sun (called *cara-saṁskāra* or *cara* correction):

26-27. The (mean) daily motion (of the Sun) multiplied by the *asus* of the (Sun's) ascensional difference and divided by the number of *asus* in a day and night (i.e., by 21600) should be subtracted from or added to the (Sun's) longitude computed for sunrise or sunset respectively, provided that the Sun is in the

northern hemishere; if the Sun is in the southern hemisphere, it should be applied reversely.[1]

In the case of other planets, this correction is determined by proportion (with the Sun's ascensional difference and the planet's mean daily motion) ; the law for its addition or subtraction (to the planet's true longitude) is the same as in the case of the Sun.

The correction due to the Sun's ascensional difference is the fourth and last correction to be applied to the Sun. By this correction allowance is made for the difference between the times of sunrise (or sunset) at the local and the *svanirakṣa* places. This is applied to the Sun's true longitude for true sunrise at the *svanirakṣa* place to get the Sun's true longitude for true sunrise at the local place.

When the Sun is in the northern hemisphere, sunrise at the local place[2] occurs earlier than that at the *svanirakṣa* place, and sunset at the local place occurs later than that at the *svanirakṣa* place. When the Sun is in the southern hemisphere, it is just the contrary. Hence the law of correction stated in the text.

The general formula for the *cara* correction is[3]

$$\textit{cara}\text{ correction} = \frac{(\text{Sun's asc. diff. in } \textit{asus}) \times (\text{planet's mean daily motion})}{21600}.$$

A rule for finding the semi-durations of the day and night:

28. (When the Sun is) in the northern hemisphere, one-fourth of the total duration of the day and night increased by the (Sun's) ascensional difference, and (when the Sun is) in the southern hemisphere, one-fourth of the total duration of the day and night diminished by the (Sun's) ascensional difference is

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[1] This rule occurs also in *KK* (Sengupta's edition ), i. 22 ; *ŚiDVṛ*, *I*, ii. 19 ; *SiŚi, I*, ii. 53; etc.

[2] The local place has been always assumed to be in the northern hemisphere, i.e., to the north of the equator.

[3] *SiŚe*, iii. 69.

the measure of half the day. The measure of half the night is obtained contrarily.[1]

This can be easily seen to be true from the celestial sphere.

Rules relating to the corrections for the Moon:

29-30. Multiply the (Moon's) mean daily motion by the Sun's equation of the centre and then divide (the product) by the number of minutes in a circle (i.e., by 21600): (the result is the *bhujāntara* correction for the Moon). Add it to or subtract it from the Moon's (mean) longitude (corrected for the longitude of the local place) in the same way as in the case of the Sun.

All remaining corrections for the Moon are prescribed as in the case of the Sun.

(The *bhujāntara* correction) for the remaining planets also is calculated from the Sun's equation of the centre.

The general formula for the *bhujāntara* correction is:

$$\textit{bhujāntara}\text{ correction} = \frac{(\text{Sun's equation of the centre}) \times (\text{planet's mean daily motion})}{21600}$$

The formula for the *bhujāntara* correction for the Moon, stated in the text, is a particular case of this.

We have seen above that in the case of the Sun four corrections are applied in the following order:

(1) the longitude correction,
(2) the *bhujāphala* correction (i. e., the equation of the centre),
(3) the *bhujāntara* correction (i. e., the correction due to the Sun's equation of the centre).
(4) the correction due to the Sun's ascensional difference.

In the case of the Moon, the same four corrections are applied in

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[1] This rule is found also in *SūSi*, ii. 62-63; *BrSpSi*, ii. 60; *KK* (Sengupta's edition), i. 23; *ŚiDVṛ*, *I*, ii. 20-21; *SiŚe*, iii. 70; *SiŚi*, *I*, ii. 52.

the following order :

(1) the longitude correction.

(2) the *bhujāntara* correction (i.e., the correction due to the Sun's equation of the centre).

(3) the *bhujāphala* correction (i.e., the Moon's equation of the centre).

(4) the correction due to the Sun's ascensional difference.

In later works, two more corrections are prescribed for the Moon. The one is equivalent to (i) the deficit of the equation of the centre of the Moon plus (ii) the evection[1], and the other is what is now called "the variation". The former occurs for the first time in the *Vaṭeśvara-siddhānta* of Vaṭeśvara (904 A.D.) and the *Laghu-mānasa* of Mañjula (932 A. D.) and the latter in the *Bījopanaya* of Bhāskara II (1150 A.D.).

The next six stanzas relate to the calculation of *tithi, karaṇa,* and *nakṣatra,* which are three out of the five principal elements of the Hindu Calendar, the other two being *yoga* and *vāra* (week-day), and to the phenomena of *vyatīpāta*. The calculations for *tithi, karaṇa* and *nakṣatra* are made for sunrise.

## Calculation of the *tithi*:

31-32. Divide the true longitude of the Moon as diminished by that of the Sun by 720 minutes (of arc); the quotient (obtained) denotes the number of *tithis* (elapsed). Multiply the remainder by 60 and divide (the product) by the difference between the (true) daily motions of the Sun and the Moon: then are obtained the *ghaṭīs, vighaṭīs,* and *asus* (elapsed of the current *tithi*). (The time in *ghaṭīs, vighaṭīs,* etc. of) the current *tithi* to elapse or elapsed is measured from sunrise.[2]

A lunar (or synodic) month is defined in Hindu astronomy from one new moon to the next. There are thirty *tithis* (lunar days) in a lunar month. The first *tithi* begins at new moon (when the Sun and the Moon have the same longitude) and continues till the Moon, due to her rapid motion, is 12° (or 720′) in advance of the Sun; the second *tithi* then begins and continues till the Moon is 24° in advance of the Sun; the third *tithi*

[1] See my paper entitled "The evection and the deficit of the equation of the centre of the Moon in Hindu Astronomy" in *Bull. Banaras Math. Soc.*, Vol. VII, No. 2, 1945.

[2] This rule occurs also in *SūSi,* ii. 66; *BrSpSi,* ii. 62; *KK* (Sengupta's edition), i. 25; *ŚiDVṛ, I,* ii. 22; *SiŚe,* iii. 71; *SiŚi, I,* ii. 66.

then begins and continues till the Moon is 36° in advance of the Sun; and so on.

A lunar month is divided also into two halves, the light half and the dark half. The light half begins at new moon and continues till full moon, and the dark half begins at full moon and continues till new moon. Evidently there are fifteen *tithis* in each half. The *tithis* falling in the two halves are numbered 1, 2, 3, ...

The text gives the method for finding the number of *tithis* elapsed since new moon, and the time elapsed at sunrise since the beginning of the current *tithi*.

Calculation of the *karaṇa*:

33. The *karaṇas* (elapsed) are obtained by taking "half the measure of a *tithi* (i.e., 360 minutes)" for the diviser, and are counted with Bava. But the number of *karaṇas* elapsed in the light half of the month should be diminished by *one*, whereas those elapsed in the dark half of the month should be increased by *one*. This is what has been stated.[1]

The *karaṇa* is half a *tithi*, so that there are 60 *karaṇas* in a lunar month. These *karaṇas* are divided into 8 cycles of 7 movable *karaṇas*, bearing the names Bava, Bālava, Kaulava, Taitila, Gara, Vaṇija, and Viṣṭi respectively, and 4 immovable *karaṇas*, bearing the names Śakuni, Catuṣpada, Nāga, and Kiṁstughna respectively.

[1] That is to say: If it is the light half of the month, divide the true longitude of the Moon as diminished by that of the Sun, reduced to minutes, by 360. The quotient diminished by *one* should be divided by seven and the remainder obtained should be counted with Bava. This gives the *karaṇa* elapsed before sunrise.

If it is the dark half of the month, subtract the longitude of the Sun from that of the Moon, and diminish that difference by six signs. Reduce it to minutes and divide by 360. The quotient increased by *one* should be divided by seven and the remainder obtained should be counted with Bava. This gives the *karaṇa* elapsed before sunrise.

The time elapsed at sunrise since the beginning of the current *karaṇa* should be determined from the remainder obtained in the division by 360, as in the case of the *tithi*.

This rule is found to occur also in *KK* (Sengupta's edition), i. 27; *ŚiDVṛ*, *I*, ii. 24; *SiŚe*, iii. 77; *SiŚi*, *I*, ii. 66.

The first round of the movable *karaṇas* begins with the second half of the first *tithi* in the light half of the month, and the eighth round ends on the first half of the fourteenth *tithi* in the dark half of the month. Thus in the light half of the month, the second *karaṇa* is Bava, the third *karaṇa* is Bālava, the fourth *karaṇa* is Kaulava, and so on; and in the dark half of the month, the first *karaṇa* is Bālava, the second *karaṇa* is Kaulava, and so on.

The four immovable *karaṇas* occur in succession after the eighth round of the cycle of the seven movable *karaṇas*.

## Calculation of the *nakṣatra*:

34. The true longitude of a planet reduced to minutes and then divided by 800 gives the number of *nakṣatras* passed over (by the planet). From the remainder (multiplied by 60 and) divided by the (planet's true daily) motion are obtained the *ghaṭīs* elapsed (since the planet's entrance into the current *nakṣatra*).[1]

We have seen that in Hindu astronomy the stars lying near the ecliptic are divided into 27 groups called *nakṣatras*.[2] Beginning with the first point of the *nakṣatra* Aśvinī,[3] the ecliptic is divided into 27 equal parts, each of 800 minutes (of arc). These divisions of the ecliptic also are called *nakṣatra* and given the same names as the twenty-seven star-groups, i. e., Aśvinī, etc. The *nakṣatras* referred to in the above stanza are these divisions of the ecliptic.

Given the longitude of a planet the above rule enables us to determine the number of *nakṣatras* passed over by the planet and the time elapsed since it crossed into the current *nakṣatra*.

## The phenomena of *vyatīpāta*:

35-36. When the sum of the (true) longitudes of the Sun and the Moon amounts to half a circle (i.e., 180°), the pheno-

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[1] This rule is found also in *SūSi*, ii. 64; *BrSpSi*, ii. 61; *KK* (Sengupta's edition), i. 24; *ŚiDVṛ*, *I*, ii. 23(i); *SiŚe*, iii. 75; *SiŚi*, *I*, ii. 67.

[2] *Vide supra*, Chapter III, stanzas 62-75(i).

[3] The first point of the *nakṣatra* Aśvinī (also called the first point of Aries) is the fixed point from which the longitudes of the planets are measured in Hindu astronomy. This point coincides with the junction-star of the *nakṣatra* Revatī, i.e. with $\zeta$ Piscium.

menon is called (*lāṭa*) *vyatīpāta;* when that (sum) amounts to a circle (i.e., 360°), the phenomenon in called *vaidhṛta (vyatīpāta)*; and when that (sum) extends to the end of the *nakṣatra* Anurādhā (i.e., when that sum amounts to 7 signs, 16 degrees, and 40 minutes), the phenomenon is called *sārpamastaka* (*vyatīpāta*).

The (*lāṭa*) *vyatīpāta* occurs when the Sun and Moon are in different courses of motion (*ayana*)[1] and their (true) declinations are equal. Its region is half a circle, but due to the Moon's latitude it may be more or less.[2]

The *sārpamastaka vyatīpāta* corresponds to the *yoga* known by the name *vyatīpāta.*

That the region of the (*lāṭa*) *vyatīpāta* is half a circle means that the (*lāṭa*) *vyatīpāta* takes place when the Sun and Moon are within half a circle measured from the first point of *nakṣatra* Aśvinī.

The phenomena of *vyatīpāta* (usually called *pāta* or *mahāpāta*) are treated in detail in later works. In the *Sūrya-siddhānta*, *Brāhma-sphuṭa-siddhānta*, *Siddhānta-śekhara*, and *Siddhānta-śiromaṇi*, etc., a whole chapter is devoted to that subject.

In modern Hindu Calendars (called Pañcāṅga) are given the *tithi*, *karaṇa*, Moon's *nakṣatra*, and *yoga* current at sunrise for every day of the year and also the times when they end and the next ones begin. The *yoga* has not been treated by Bhāskara I, but it forms one of the five important elements of the Hindu Calendar. Like the *nakṣatras*, the number of these *yogas* is also twenty-seven. The method of finding the *yoga* passed over and the time elapsed at sunrise since the commencement of the current *yoga* is similar to that prescribed for the *nakṣatra*. The difference is that in the case of the *yoga* calculation is made with the sum of the longitudes of the Sun and the Moon, whereas in the case of the *nakṣatra* calculation is made with the help of the longitude of the Moon only. The first *yoga* (called Viṣkambha) begins when the sum of the longitudes of the Sun and moon is zero, the second *yoga* (called Prīti) begins when

[1] That is to say, when one has northward motion and the other has southward motion.

[2] For details, see *SiŚi, I,* xii.

that sum amounts to 13°20′, the third yoga (called Āyuṣmān) begins when that sum amounts to 26°40′, and so on.[1]

The remaining chapter relates to the planets, Mars, Mercury, Jupiter, Venus, and Saturn.

Calculations relating to the planets, Mars, etc.:

37. (In the case of the planets, Mars, etc.) the determination of the direct and inverse Rsines (relating to the *kendra*, i.e., *mandakendra* and *śīghrakendra*) as also the calculation of the *bhujā* and *koṭi* etc. is to be made as in the case of the Sun. The differences (in the case of Mars, etc.) will now be stated.

The *mandakendra* and the *śīghrakendra* are defined by the following equations:

*mandakendra* = longitude of the mean planet — longitude of the planet's *mandocca* (apogee).

*śīghrakendra* = longitude of the planet's *śīghrocca*—longitude of the true-mean planet.[2]

A rule for finding the (planet's) corrected epicycle:

38-39(i). Multiply the Rsine or Rversed-sine (of the part of the *kendra* lying in the current quadrant[3]), according as the (current) quadrant is odd or even, by the difference between

[1] The names of the 27 *yogas* are: (1) Viṣkambha, (2) Prīti, (3) Āyuṣmān, (4) Śaubhāgya, (5) Śobhana, (6) Atigaṇḍa, (7) Sukarmā, (8) Dhṛti, (9) Śūla, (10) Gaṇḍa, (11) Vṛddhi, (12) Dhruva, (13) Vyāghāta, (14) Harṣaṇa, (15) Vajra, (16) Siddhi, (17) Vyatīpāta, (18) Varīyān, (19) Parigha, (20) Śiva, (21) Siddha, (22) Sādhya, (23) Śubha, (24) Śukla, (25) Brahmā, (26) Indra, and (27) Vaidhṛta.

There is another system of twenty-eight *yogas*, beginning with Ānanda. In some Hindu calendars *yogas* of this system are also given for each day of the month. But these *yogas* are only of astrological interest.

[2] See *infra*, chapter vii, stanza 12.

[3] The *kendra* is said to be in the first quadrant if it is less than 90°, in the second quadrant if it is between 90° and 180°, and so on.

the (planet's) own epicycles (for the beginnings of the odd and even quadrants) and then divide (the product) by the radius; and apply the result (thus obtained) to the (planet's) epicycle (for the beginning of the current quadrant). Subtract (that result), when the epicycle for (the beginning of) the current quadrant is greater; add (that result), when the epicycle for (the beginning of) the current quadrant is smaller. Thus is obtained the (planet's) corrected epicycle.[1]

In the case of the Sun and the Moon, which move around the Earth, we have seen that only one epicycle is contemplated which is meant to account for the eccentricity of the orbit. In the case of the planets, Mars, Mercury, Jupiter, Venus, and Saturn, which revolve round the Sun, two kinds of epicycles are envisaged, (i) *manda*, and (ii) *śighra*. We shall presently see how these epicycles are utilized to explain the motion of the planets.

Unlike the mean epicycle for the Sun or Moon, the *manda* and *śighra* epicycles for Mars, etc., are supposed to vary from place to place. Their values at the beginnings of the odd and even quadrants are given in the seventh chapter.[2] Those for any other point of the orbit are determined by the method taught in the stanza under consideration.

Let $\alpha'$ and $\beta$ be the epicycles (*manda* or *śighra*) of a planet for the beginnings of the odd and even quadrants respectively. Then (1) if the planet be in the first quadrant (of the *kendra*), say at P, and its *kendra* be $\theta$,

$$\text{epicycle at P} = \alpha + \frac{(\beta - \alpha) \times \text{Rsin}\,\theta}{\text{R}} \quad (\text{when } \alpha < \beta)$$

$$= \alpha - \frac{(\alpha - \beta) \times \text{Rsin}\,\theta}{\text{R}} \quad (\text{when } \alpha > \beta)$$

and (2) if the planet be in the second quadrant (of the *kendra*), say at Q, and its *kendra* be $90° + \phi$,

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[1] This rule occurs also in *SūSi*, ii. 38 and *SiŚe*, iii. 22.

[2] Stanzas 13-16.

$$\text{epicycle at } Q=\beta-\frac{(\beta-\alpha)\times \text{Rversin } \phi}{R}, \text{ (when } \alpha<\beta).$$

$$=\beta+\frac{(\alpha-\beta)\times \text{Rversin } \phi}{R}, \text{ (when } \alpha>\beta).$$

Similarly, in the third and fourth quadrants.

Rule for finding the *kendraphala* (*i.e.*, *mandakendra-phala* or *śīghrakendra-phala*):

39(ii). By that (corrected epicycle) multiply the Rsine of the *kendra* of the desired planet and then divide (the product obtained) by 80; this is known as the (*kendra*) *phala*.

That is,

*mandakendraphala*

$$=\frac{(\text{corrected } \textit{manda} \text{ epicycle})\times \text{Rsin } (\textit{mandakendra})}{80},$$

and *śīghrakendraphala*

$$=\frac{(\text{corrected } \textit{śīghra} \text{ epicycle})\times \text{Rsin } (\textit{śīghrakendra})}{80}.$$

By the *mandakendraphala* is meant the *bāhuphala* derived from the planet's corrected *manda* epicycle, and by the *śīghrakendraphala* is meant the *bāhuphala* derived from the planet's corrected *śīghra* epicycle. The method of finding the *bāhuphala* is the same as taught in the case of the Sun.

In what follows we shall see how the *mandakendraphala* and the *śīghrakendraphala* are used in finding the true geocentric longitudes of the planets. Their significance will also then become clear.

Procedure to be adopted for finding the true geocentric longitude in the case of Mars, Jupiter, Saturn, Mercury and Venus:

40-44. Calculate half the arc corresponding to the (planet's) *mandakendraphala* and apply that to the (planet's) mean longitude depending on the quadrant (of the planet's *kendra*) as in the case of the Sun.

(Then calculate the *śīghrakendraphala*). Multiply the radius by the *śīghrakendraphala* and divide (the product) by the (planet's) *śīghrakarṇa*; then reduce that to arc. Apply half of that arc to the longitude obtained above, reversely (i.e., add when the *śīghrakendra* is in the half orbit beginning with the sign Aries and subtract when the *śīghrakendra* is in the half orbit beginning with Libra).

Therefrom calculate (the arc corresponding to) the *manda-(kendra)phala* and apply the whole of that to the mean longitude of the planet. Thus are obtained the true-mean longitudes of Mars, Saturn, and Jupiter.

The true-mean longitude corrected for the arc derived from the *śīghrakendraphala*[1] (literally, the arc corresponding to the result derived from the longitude of the *śīghrocca* minus the true-mean longitude of the planet) is to be known as the true longitude. The method (to be used) for the remaining planets (i.e., Mercury and Venus) is now being told.

The longitude of the (planet's) *mandocca* (i.e., apogee) reversely increased or decreased by half the arc derived from the *śīghrakendraphala* determines the true-mean longitude (of the planet). And that (true-mean longitude) corrected for the arc derived from the *śīghra(kendraphala)* is known as the true longitude.[2]

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[1] 'The arc derived from the *śīghrakendraphala*' is obtained by first multiplying the radius by the *śīghrakendraphala* and dividing by the *śīghrakarṇa* and then reducing that to arc. See stanza 41.

The rule given in stanzas 40-43 is found also in *Ā*, iii. 23; *LBh*, ii. 32-35; *ŚiDVṛ*, *I*, ii. 30-34; *TS*, ii. 55-65, 66(i).

[2] What is meant here may be explained as follows: Subtract the mean longitude of the planet from the longitude of the planet's *śīghrocca*. Multiply the Rsine of that by the planet's corrected *śīghra* epicycle and divide by 80: the result is the planet's *śīghrakendraphala*. Multiply that by the radius and divide by the planet's *śīghrakarṇa*, and reduce the resulting Rsine to the corresponding arc. Add half of it to or subtract that from the longitude of the planet's *mandocca* according as the *śīghrakendra* of the planet is in the half orbit beginning with the sign Libra or Aries. Treat this

We explain below the motion of the planets, Mars, Mercury, Jupiter Venus, and Saturn, according to the Hindu epicyclic theory.

Consider Fig. 14. E is the Earth. The bigger circle USM centred at E is the deferent (*kakṣāvṛtta*). The point U on the deferent is the planet's *mandocca* (apogee). M is the position of the mean planet which is supposed to move on the deferent with mean velocity from west to east (in the anticlockwise direction indicated by an arrow). The small circle centred at M is the planet's *manda* epicycle corresponding to the position M of the mean planet: this *manda* epicycle is determined as taught in stanzas 38-39(i). EC is equal to $MM_1$, $M_1$ and C are joined by a line which intersects the deferent at the point S. $MM_1$ and ES are produced to meet at the point T′. This point T′ is, according to the Hindu astronomers, the position of the true-mean planet. The so called true-mean planet is assumed to move on the periphery of the true epicycle of radius MT′ centred at M with the same velocity as the mean planet has relative to the apogee but in the opposite sense (i.e., clockwise). The point S denotes the position of the true-mean planet on the deferent.

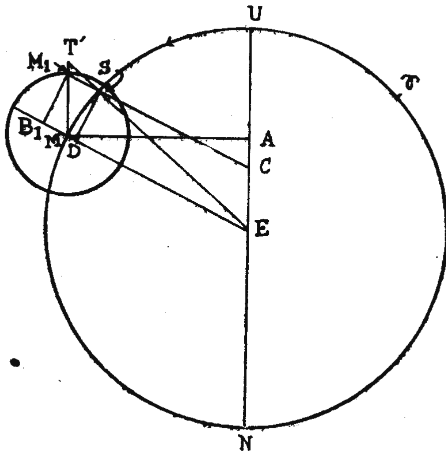


Fig. 14

sum or difference as the correct longitude of the planet's *mandocca*. Therefrom calculate the arc corresponding to the planet's *mandakendraphala* and apply that to the planet's mean longitude. Thus is obtained the planet's true-mean longitude. Then calculate the arc derived from the planet's *śīghrakendraphala* and apply that to the true-mean longitude of the planet. Then is obtained the true longitude of the planet (Mercury or Venus).

The rule stated in stanza 44 occurs also in *Ā*, iii. 24; *LBh*, ii. 37-38; and *ŚiDVṛ*, *I*, ii. 35. The method prescribed here for finding the true longitudes of Mercury and Venus has been prescribed for all the planets in the *Karaṇa-prakāśa* (ii (b). 3, 4), the *Graha-lāghava* (iii. 10), the *Ravi-siddhānta-mañjarī* (ii. 1), and the *Karaṇa-kaustubha* (iii. 19), etc., all of them being calendrical works.

If ♈ be the first point of Aries, then ∠ ME♈ (or arc MU♈) is the mean longitude of the planet, and ∠SE♈ (or arc SU♈) is the true-mean longitude of the planet. The arc MS by which the true-mean longitude of the planet differs from the mean longitude of the planet is obtained as follows:

Let MA be the perpendicular from M on EU, $M_1B_1$ and SD the perpendiculars from $M_1$ and S on EM. Then comparing the triangles $M_1B_1M$ and MAE, we have

$$M_1B_1, \text{ i.e., } SD = \frac{MA \times MM_1}{EM}$$

$$= \frac{\text{Rsin } (\textit{bāhu} \text{ due to } \textit{mandakendra}) \times (\text{radius of corrected } \textit{manda} \text{ epicycle})}{R}$$

$$= \frac{(\text{corrected } \textit{manda} \text{ epicycle}) \times \text{Rsin } \theta}{80}, \qquad (1)$$

where $\theta$ denotes the *bāhu* due to *mandakendra*.[1]

Reducing the right-hand side of (1) to the corresponding arc, we get the arc MS.

This arc MS has been referred to by Bhāskara I as the arc corresponding to the *mandakendraphala*, because it corresponds to $M_1B_1$ which denotes the *mandakendraphala*. Generally it is known as *mandaphala*. It is subtracted from or added to the mean longitude of the planet, according as the *mandakendra* is less than or greater than 180°, as in the case of the Sun and Moon.[2] Thus

true-mean longitude = mean longitude ∓ *mandaphala*,

according as the *mendakendra* is less than or greater than 180°.

Now consider Fig. 15. Here also E is the Earth and the bigger circle centred at E is the deferent (*kakṣāvṛtta*); U is the planet's *mandocca* ("apogee") and V the planet's *śīghrocca*. S is the position of the true-mean planet on the deferent. The small circle centred at S is the planet's *śīghra* epicycle: it is derived as taught in stanzas 38-39(i). ST is drawn parallel to EV. Then T denotes the position of the true planet. ET is called the *śīghrakarṇa*.

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[1] The *bāhu* due to *mandakendra* is derived in the same way as in the case of the Sun. The corrected *manda* epicycle used in this last result is that divided by 4½.

[2] It may be pointed out that in the case of the Sun and Moon the *mandaphala* is the equation of the centre, called *bāhuphala* by Bhāskara I.

The true planet is assumed to move on the *śīghra* epicycle with the same angular velocity as the true-mean planet appears to have in the deferent with respect to the *śīghrocca*. Whereas the true-mean planet appears to move on the deferent (in the clock-wise direction) away from the *śīghrocca*, the true planet is supposed to move on the epicycle, centred at the true-mean planet, in the anti-clock-wise direction, so that the line ST is always parallel to EV.

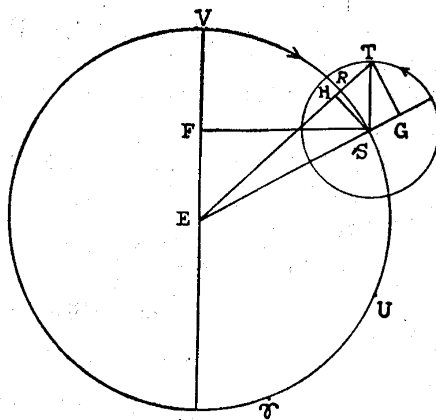


Fig. 15

Let the line ET intersect the deferent at R. Then R denotes the true position of the planet on the deferent. If ♈ be the first point of Aries, then

∠ SE♈ (or arc SU♈) is the true-mean longitude of the planet, and ∠ RE♈ (or arc RU♈) is the true longitude of the planet.

The arc RS of the deferent, by which the true longitude of the planet differs from the true-mean longitude, denotes the planet's *śīghra* correction (usually called *śīghraphala*). It is derived as follows:

Let SF, TG, and SH be the perpendiculars drawn from S, T, and S on EV, ES produced and ET respectively.

Now arc VS = ♈V − ♈S,

i.e., *śīghrakendra* = (longitude of *śīghrocca*) − (longitude of true-mean planet).

Let this *śīghrakendra* (reduced to *bāhu*, if necessary) be denoted by $\phi$. Then comparing the similar triangles TGS and SFE, we get

$$TG = \frac{SF \times ST}{ES},$$

But $SF = R\sin\phi$,

and $\frac{ST}{ES} = \frac{\textit{śīghra}\text{ epicycle}}{360} = \frac{\text{corrected } \textit{śīghra}\text{ epicycle}^{1}}{80}.$

[1] As pointed out earlier, this corrected epicycle is divided by 4½.

Therefore $TG = \frac{\text{Rsin } \phi \times (\text{corrected } \acute{s}\bar{\imath}ghra \text{ epicycle})}{80}$.

Again from the similar triangles ESH and ETG, we have

$$SH = \frac{TG \times ES}{ET},$$

i.e., Rsin (arc RS)

$$= \frac{\text{Rsin } \phi \times (\text{corrected } \acute{s}\bar{\imath}ghra \text{ epicycle}) \times R}{80 \times \acute{s}\bar{\imath}ghrakar\d{n}a},$$

Therefore arc RS or *śīghraphala* is the arc corresponding to the right hand side of this equality.

This *śīghraphala* is added to or subtracted from the true-mean longitude of the planet according as the *śīghrakendra* is less than 180° or greater than 180°, because in the former case the true planet is in advance of the true-mean planet and in the latter case the true planet is behind the true-mean planet. Thus

true longitude = true-mean longitude ± *śīghraphala*,

according as the *śīghrakendra* is less than or greater than 180°.

The true longitude of the planet thus obtained was found to differ from the actual longitude determined from observation. Āryabhaṭa I supposed that the error was due to the inaccuracy of the *mandakendra* (*manda* anomaly). So to get rid of the error, in the case of the superior planets (Mars, Jupiter and Saturn), he applied in succession (i) half the planet's *mandaphala*, and (ii) half the planet's *śīghraphala* to the *mandakendra* of the planet; and in the case of the inferior planets (Mercury and Venus), he applied half the planet's *śīghraphala* to the *mandakendra* of the planet From the *mandakendra* thus corrected, he calculated and applied in succession the *mandaphala* and the *śīghraphala* corrections to the mean longitude of the planet. The same procedure has been followed by the pupils and followers of Āryabhaṭa I. Hence the rules stated in stanzas 40-44.

The device contemplated by Āryabhaṭa I continued to be used by his followers, but it was never very successful. Naturally, it never came into general use. Several other devices were attempted from time to time by later astronomers.

A rule relating to the eccentric theory:

45-46. The wise (astronomer) should apply the eccentric theory here ( i. e., in the case of the planets Mars, etc. ) also. (Under this theory the *mandocca* and *śīghrocca* operations are as follows:)

To the longitude of the *mandocca* ("apogee"), apply (the *spasṭa-bhuja* due to the *mandakendra,* as a positive correction) in the manner prescribed above (in stanza 22). From the longitude of the *śīghrocca* subtract the *spaṣṭa-bhuja* (due to the *śīghra-kendra*) (as follows):

(When the *śīghrakendra* is) in the first and second quadrants, subtract from the longitude of the *śīghrocca* the *spaṣṭa-bhuja* itself and that subtracted from half a circle (i.e., 180°) respectively; (when the *śīghrakendra* is) in the remaining quadrants (i.e., third and fourth), subtract that (*spaṣṭa-bhuja*) as increased by half a circle and that (*spaṣṭa-bhuja*) subtracted from a circle respectively.

In Fig. 16, let the circle UMN centred at E, the Earth, be the concyclic (*kakṣāvṛtta*), the circle centred at C the *manda* eccentric (*manda-prativṛtta*), U the planet's *mandocca* (apogee), and M the mean position of the planet. Let $MM_1$ be parallel to EU; and let S be the point where $CM_1$ intersects the concyclic, and T′ the point where $MM_1$ and ES produced meet. Then T′ is the position of the true-mean planet and S the position of the true-mean planet on the concyclic. If ♈ be the first point of Aries, then

arc ♈US is the true-mean longitude of the planet.

When the mean planet is in the first quadrant beginning with U, as shown in the figure,

arc ♈US=♈U+US,

i. e., true-mean longitude = longitude of the planet's apogee + *spaṣṭa-bhuja*.[1]

When the mean planet is in the second anomalistic quadrant, the *spaṣṭa-bhuja* is the arcual distance of the true-mean planet from the perigee M. Thus, in this case

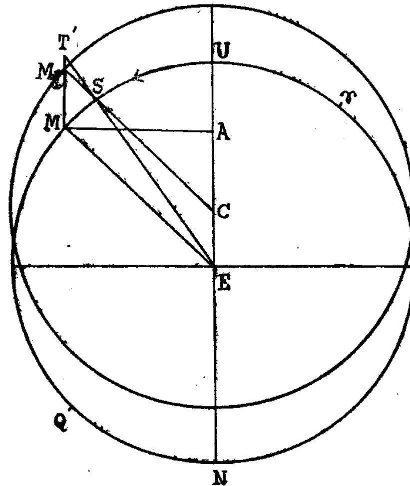


Fig. 16

[1] As in the case of the Sun, arc MU is the *bāhu* or *bhuja* (due to planet's *mandakendra*) and arc SU is the *spaṣṭa-bhuja*.

true-mean longitude = longitude of planet's apogee
+ (180° — *spaṣṭa-bhuja*).

Similarly, when the mean planet is in the third anomalistic quadrant,

true-mean longitude = longitude of the planet's apogee
+ (180° + *spaṣṭa-bhuja*);

and when the mean planet is in the fourth anomalistic quadrant

true-mean longitude = longitude of the planet's apogee
+ (360° — *spaṣṭa-bhuja*).

The *spaṣṭa bhuja* is obtained by the the following formula as in the case of the Sun:

$$\text{Rsin}\ (\textit{spaṣṭa-bhuja}\ \text{SU}) = \frac{\text{MA} \times \text{ES}}{\text{ET}'} = \frac{\text{Rsin}\ \theta \times \text{R}}{H},$$

where $\theta$ in the *bāhu* or *bhuja* (due to the planet's *mandakendra*), R is the radius, and $H$ the planet's distance ET′ which is called *mandakarṇa* and determined by the method of successive approximations as in the case of the Sun. (See stanza 55)

Now consider Fig. 17. The circle VSU, centred at E, is the concyclic, V is the *śighrocca*, and S is the true-mean planet. The circle centred at $C_1$ is the *śighra* eccentric. The point T, where the line through S drawn parallel to EV meets the eccentric, is the true planet. R is the point where ET intersects the concyclic. ♈ is the first point of Aries.

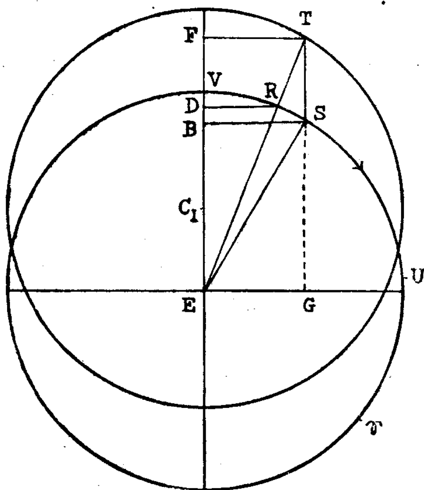



Fig. 17

When the true-mean planet is in the first quadrant beginning with V and measured in the clockwise direction as shown in the figure,

true longitude = arc ♈SR = arc ♈SV — arc VR
= longitude of the *śighrocca* — *spaṣṭa-bhuja*.

When the true-mean planet is in the second quadrant,
true longitude=longitude of the *śighrocca* — (180° — *spaṣṭa-bhuja*).
When the true-mean planet is in the third quadrant,
true longitude=longitude of the *śighrocca* — (180°+*spaṣṭa-bhuja*).
When the true-mean planet is in the fourth quadrant,
true longitude=longitude of the *śighrocca* — (360° — *spaṣṭa-bhuja*).
The *spaṣṭa-bhuja* due to the *śighrocca* is determined by the formula :

$$\text{Rsin } (spaṣṭa\text{-}bhuja) = \frac{\text{SB} \times \text{ER}}{\text{ET}}$$

$$= \frac{\text{Rsin } \phi \times \text{R}}{H'},$$

where $\phi$ is the *bāhu* (due to the *śighrakendra*), R the radius, and $H'$ the distance ET of the true planet, called *śighrakarṇa*.

A rule for finding the *mandakarṇa* and *śighrakarṇa*:

47. Multiply the radius by the (planet's) corrected epicycle and then divide (the product) by 80; then subtract the quotient from or add that to the Rsine of the corresponding *koṭi* (due to the *kendra*) in accordance with the quadrant (of the *kendra*) : and then calculate the (planet's) *karṇa* as before.

This method is analogous to that stated for the Sun and Moon in stanzas 19-20. The important thing to be noted is that in finding the *manda-karṇa* we have to apply the method of successive approximations as in the case of the Sun and Moon, whereas in finding the *śighrakarṇa* we have to apply the method only once.[1] The reason for this difference must have become clear to the reader from the epicyclic and eccentric theories, which have been explained above in detail.

Procedure to be adopted for finding the true longitude of the planets under the eccentric theory:

48-54. Add half the difference between the (mean) planet corrected by the *mandocca* operation and the mean planet to or subtract that from the mean planet according as the (mean) planet as corrected for the *mandocca* operation is greater or less (than the mean planet). (The planet thus obtained is call-

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[1] See *infra*, stanza 55.

ed the once-corrected planet). Then correct it by the *śīghrocca* operation. (The planet thus obtained is called the twice-corrected planet). Then find the difference between the two planets thus obtained (i.e., the once-corrected and twice-corrected planets); divide that by two; and apply it to the once-corrected planet, as before. Whatever is thus obtained should be again corrected by the *mandocca* operation. Next calculate the difference between the twice-corrected planet, as corrected by the *mandocca* operation, and that (twice-corrected planet). Apply whatever be the difference between the twice-corrected planet as corrected by the *mandocca* operation and the twice-corrected planet to the mean longitude of the planet, as before. That (i.e., the resulting longitude) corrected by the *śīghrocca* operation is the true longitude of the planet.

Thus has been stated the method for finding (the true longitudes of) Mars, Saturn, and Jupiter under the eccentric theory. Now is described the procedure to be adopted in the case of the remaining planets (viz. Mercury and Venus).

(First of all obtain the mean planet as corrected by the *śīghrocca* operation). Then add half the difference between the mean planet corrected by the *śīghrocca* operation and the mean planet to or subtract that from the planet's *mandocca*, according as the mean planet corrected by the *śīghrocca* operation is less or greater (than the mean planet). Thus is obtained the true *mandocca*. Then find out, by the method under the eccentric theory,[1] the correction due to the true *mandocca* for Mercury as well as for Venus. The mean longitudes of Mercury and Venus each corrected for that and thereafter for the correction due to the *śīghrocca* are known as true longitudes of the planets.

The procedure for finding the true longitudes of the superior and inferior planets stated in stanzas 40-44 according to the epicyclic theory has been translated in the above stanzas into the eccentric theory. The results in both cases are the same.

[1] The method is to find the difference between (i) the mean planet corrected by the *mandocca* operation and (ii) the mean planet.

Further instructions relating to *mandakarṇa* and *śīghrakarṇa* :

55. When the Rsine of the greatest correction (*antyaphala*) is to be subtracted from the Rsine of the *koṭi* (due to the *kendra*), but subtraction is not possible, then subtract reversely (i. e., the latter from the former).[1] Determine the *mandakarṇa* by the method of successive approximations (as in the case of the Sun or Moon) and the *śīghrakarṇa* by a single application of the process (as taught in stanza 47).

In the case of the *mandakarṇa*, the Rsine of the greatest correction is equal to the radius of the corrected *manda* epicycle, i.e., to

$$\frac{(\text{corrected } manda \text{ epicycle}) \times R}{80},$$

and in the case of the *śīghrakarṇa*, the greatest correction is equal to the radius of the corrected *śīghra* epicycle, i.e., to

$$\frac{(\text{corrected } \acute{s}\bar{\imath}ghra \text{ epicycle}) \times R}{80}.$$

A rule pertaining to the direct and retrograde motions of a planet :

56-57. Having applied to the longitude of the *śīghrocca* half the difference between the true and mean longitudes (of a planet) positively or negatively, depending upon (whether) the mean longitude (of the planet is greater or less than the true longitude), determine whether the motion of the planet is *vakra* or *ativakra* or whether it is the end of the *vakra* motion.

The true longitude of the planet having been subtracted from the longitude of the (corrected) *śīghrocca*, when the difference is 4 signs, the planet is about to take up *vakra* (retrograde) motion; when 6 signs, it is in *ativakra* (maximum retrograde) motion; and when 8 signs, it soon abandons the regressive path.[2]

The difference between the true longitudes of a planet computed for (sunrise on) the day to elapse (i.e., today) and

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[1] Reference is to the rule given in stanza 47.

[2] This rule is found also in *SiŚe*, iii. 59; *BrSpSi*, ii, 50-51; *ŚiDVṛ*, *I*, ii. 42.

for (sunrise on) the day elapsed (i.e., yesterday) is the (true) daily motion (of the planet for the day elapsed).

Hindu astronomers have recognised eight kinds of motion of the planets. According to the *Sūrya-siddhānta*,[1] these are : (1) *vakra* (beginning of regression), (2) *ativakra* (maximum regression), (3) *kuṭila* (end of regression and beginning of direct motion), (4) *manda* (slow), (5) *mandatara* (slower), (6) *sama* (mean), (7) *śīghra* (fast), and (8) *śīghratara* (faster). Of these, says the author of the *Sūrya-siddhānta*, the first three are the different kinds of retrograde motion and the last five the various forms of direct motion.[2] The above stanzas 56 and 57 deal with the three varieties of retrograde motion. The details of the five varieties of direct motion are given by Śrīpati in his *Siddhānta-śekhara*.[3] According to him, the motion is said to be "very fast", when the planet (measured from its *śīghrocca*) is in the beginning of the sign Aries or Pisces ; "fast", when in the beginning of Taurus or Aquarius; "mean" when in the beginning of Gemini or Capricorn ; "slow", when in the first half of Cancer or in the last half of Sagittarius ; and "very slow", when in the first half of Sagittarius or in the last half of Cancer.

The following table gives the *śīghrakendras* of the planets when they take up retrograde motion according to various Hindu authorities :

**Sighrakendras of the planets when they take up retrograde motion.**

| Planet | *Śīghrakendra* | | | | |
|---|---|---|---|---|---|
| | *BrSpSi* (ii.48), *ŚiDVṛ* (*I*,ii. 47), *KPṛ* (iii. 8), *SiŚe* (iii. 58), *SiŚi* (*I*, ii. 41) | *KKau* (ii.23), *GLā* (iii.15) | *MSi* (iii.31) | *VVSi* (ii.30), *SūSi* (ii.53-54) | *PiSi*, *KK* (iii. 8-17) |
| Mars | 163° | 163° | 163° | 164° | 164° |
| Mercury | 145° | 145° | 145° | 144° | 146° |
| Jupiter | 125° | 125° | 125° | 130° | 125° |
| Venus | 165° | 167° | 166° | 163° | 165° |
| Saturn | 113° | 113° | 113° | 115° | 133° |

[1] ii. 12. [2] *SūSi*, ii.13. [3] iii. 60.

A rule for finding the true daily motion (called *jīvābhukti*) of the planets :

58-63. Multiply the (planet's) own (mean) daily motion by the current Rsine-difference relating to the *mandocca* (i.e., the current Rsine-difference corresponding to the *mandakendra* of the planet) and again by the (planet's) own (corrected *manda*) epicycle ; then divide (the product) by the number of minutes in a sign as multiplied by 10 (i.e., by 18000[1]). Add half of that to or subtract that from the (planet's) mean daily motion according to (the law of addition and subtraction in) the (four) quadrants.[2] (Thus is obtained the once-corrected daily motion).

Subtract that from the daily motion of the *śighrocca*. Multiply whatever is obtained (i.e., *śighrakendrajyāgatiphala*) by proceeding with the remainder in accordance with the rule "*kendrāntyajīvā* etc." (stated in the previous stanza)[3] by the radius and divide by the *śighrakarṇa* (of the planet) ; (and reduce the resulting Rsine to the corresponding arc). Add half of that (arc) to or subtract that from (the once-corrected daily motion) in accordance with the law (of addition and subtraction) for the correction due to *śighrocca*. (Thus is obtained the twice-corrected daily motion).

Then add the entire of the *mandakendrajyāgatiphala*[4] (derived from the current Rsine-difference corresponding to the

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[1] This number is the product of 225 and 80.

[2] See *supra* stanza 5.

[3] That is to say, multiply the remainder by the current Rsine-difference corresponding to the *śighrakendra* of the once-corrected planet and also by the planet's corrected *śighra* epicycle and divide the product by 18000 : the result is the *śighrakendrajyāgatiphala*.

[4] Multiply the twice-corrected daily motion by the current Rsine-difference corresponding to the *mandakendra* of the twice-corrected planet and also by the planet's corrected *manda* epicycle and divide the product by 18000 : the result is the *mandakendrajyāgatiphala*.

*mandakendra* of the twice-corrected planet) to or subtract that from the (planet's) mean daily motion (according to the law of addition and subtraction in the four quadrants). Set down the result at two places. At one place (subtract that from the daily motion of the *śīghrocca* and then) calculate (the arc corresponding to) the *śīghrakendrajyāgatiphala*.[1] Add the entire of that (arc) to or subtract that from the result kept at the other place (according to the law of addition and subtraction in the four quadrants). Thus is obtained the desired true daily motion (of the planet).

When the result derived from the *śīghra* operation (i.e., the arc corresponding to the *śīghrakendrajyāgatiphala*) cannot be subtracted from that[2], the difference between the two then denotes the value of the true daily motion and the planet is said by the learned to be retrograde.[3]

This is the method for finding the true daily motion in the case of Jupiter, Saturn, and Mars. Now is being described the method for Venus and Mercury.

Increase or diminish (as usual) the mean daily motion of Venus or Mercury by the entire motion-correction (i. e., *mandakendrajyāgatiphala*) determined from the corrected *mandakendra* and also by that obtained by proceeding according to the rule

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[1] The process is : Multiply the difference obtained after subtraction from the daily motion of the *śīghrocca* by the current Rsine-difference corresponding to the *śīghrakendra* and also by the corrected *śīghra* epicycle and divide that product by 18000 : the result is the *śīghrakendrajyāgatiphala*. Multiply that by the radius and divide by the *śīghrakarṇa*, and reduce that to the corresponding arc.

[2] That is, the result kept at the other place.

[3] This rule is found also in *ŚiDVṛ*, *I*, ii. 38-40.

"*śighrāntyajīvā* etc.".[1] This (sum or difference) is the true daily motion (of Venus or Mercury). Thus has been stated the difference of procedure (in the case of the superior and inferior planets).

The daily motion thus obtained is always very nearly equal to the true daily motion and should be made use of in practical calculations.

The above rules relate to the determination of the true daily motion of the planets, Mars, Mercury, Jupiter, Venus, and Saturn, and seem to have been inspired by the rule of Aryabhata I's midnight day-reckoning which has been adopted by Brahmagupta in his *Khaṇḍa-khādyaka*[2]. They are different from the analogous rules found in the other works on Hindu astronomy.[3]

They have been derived by taking the difference between the longitudes of the planets for two consecutive days as in the case of the Sun and Moon.[4] The rules differ in the case of superior and inferior planets because the methods of finding the true longitudes in the two cases differ.

The daily motion obtained by the application of the above rules is known as *jīvābhukti* as in the case of the Sun and Moon. It is probably

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[1] That is to say: Multiply the mean daily motion by the current Rsine-difference corresponding to the *mandakendra* determined from the corrected *mandocca* (see stanza 53) and also by the corrected *manda* epicycle and divide the product by 18000: the result is the *mandakendrajyāgatiphala*. Add it to or subtract it from the mean daily motion of the planet (as necessary). Subtract the sum or difference thus obtained from the daily motion of the *śīghrocca*. Multiply the difference by the current Rsine-difference corresponding to the *śīghrakendra* and also by the corrected *śīghra* epicycle and divide the product by 18000. Multiply that by the radius and divide by the *śīghrakarṇa*, and reduce that to the corresponding arc. Add it to or subtract it from the mean daily motion already corrected for the *mandakendrajyāgatiphala*.

[2] See *KK* (Sengupta), ii. 19; *KK* (Babua Misra), ii. 26. Also see Pṛthūdaka's comm. on this stanza.

[3] e. g. by Lalla, *ŚiDVṛ*, *I*, ii. 40.

[4] See *supra* stanzas 14-17.

because the rules depend upon the use of the table of Rsine-differences. It is assumed that the Rsines very uniformly, so the results obtained from the above rules are only approximate as the author himself admits.

The true daily motion is required for the purpose of computing displacements of the planets. In the case of the Sun and the star-planets (Mars, Mercury, etc.), the daily motion is small enough and not much error is introduced by using the *jīvābhukti* but in the case of the Moon the daily motion is so much that the use of the *jīvābhukti* in computing displacemets of the Moon may cause serious error. This thing was noticed by the author of the present work himself who in his smaller work, the *Laghu-Bhāskarīya*[1], has criticised the *jīvābhukti* and has preferred the *karṇabhukti*, i.e., the daily motion derived by the use of the instantaneous distance of the planet. Lalla, the author of the *Śiṣya-dhī-vṛddhida*, also has pointed out the above-mentioned discrepancy of the *jīvābhukti*.[2] In the works of Brahmagupta, Lalla, and Śrīpati, the rules of finding the true daily motion of the planets are based on the distances of the planets.[3]

The object of devising rules depending on the instantaneous distances of the planets was essentially to obtain thc instantaneous velocities of the planets, but the aim was not wholly achieved by the rules given by Brahmagupta, Lalla, and Śrīpati. For the velocity obtained by their methods turned out to be the same as the mean daily motion of the planet at the intersection of the concentric and the eccentric, which was wrong.[4] An accurate rule for the instantaneous velocity of a planet was given by Mañjula (932 A. D.) and by Āryabhaṭa II (c. 950 A.D.). The method was fully explained by Bhāskara II (1150 A. D.). More accurate rules occur in the *Tantra-saṅgraha* of Nīlakaṇṭha,[5]

Instantaneous velocity is known in Hindu astronomy by the terms *tātkālikī-gati, tatkāla-gati, tatkṣaṇa-gati, tatsamayajā-gati*, and *velā-bhukti*.

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[1] ii. 14-15.

[2] *ŚiDVṛ*, *I*, ii. 43.

[3] The rules are given in *BrSpSi*, ii. 41-42; *ŚiDVṛ*, *I*, ii. 45-46; and *SiŚe*, iii. 42-43 respectively.

[4] See *ŚiDVṛ*, *II*, i. 13(ii) and also *SiŚi*, *II*, v. 39.

[5] The rules of Mañjula, Āryabhaṭa II, Bhāskara II, and Nīlakaṇṭha are given in *LMā*, ii. 4(ii), *MSi*, iii. 15 (ii). 27; *SiŚi*, *I*, ii. 37, 39; and *TS*, ii. 51-52 respectively.

A rule for finding the longitudes of the Sun and the Moon at the end of the *parva-tithi*:

64. Multiply the unelapsed part of the (*parva*) *tithi* or the elapsed part of the (next) *tithi* by the (true) daily motions of the Sun and the Moon and divide (each product) by the difference between the (true) daily motions (of the Sun and Moon). The longitudes of the Sun and the Moon[1] increased or diminished (in the two cases respectively) by the quotients (thus obtained) should be known as the longitudes agreeing to minutes of the Sun and Moon—the causes of the performances of the world.[2]

By the *parva-tithi* is meant the fifteenth *tithi* called *purṇimā* (i.e., full moon day) or the thirtieth *tithi* called *amāvāsyā* (i.e., new moon day). The end of the former occurs when the Sun and Moon are in opposition in longitude, and the end of the latter occurs when the Sun and Moon are in conjunction in longitude.

At the time of opposition of the Sun and Moon, the longitudes of the Sun and Moon differ by six signs but otherwise agree to minuts of arc. At the time of conjunction of the Sun and Moon, the longitudes of the Sun and Moon are exactly the same and therefore agree to minutes of arc. Hence the above rule.

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[1] For sunrise on the *parva-tithi* in the first case and for sunrise on next *tithi* in the second case.

[2] The same rule is stated in *SūSi*, iv. 8; *PSi*, vi. 1; *MSi*, v. 4(ii)-5 (i); *SiŚe*, iii. 84; and *SiŚi*, *I*, ii. 70; Nīlakaṇṭha (*TS*, iv. 1-8) and Kamalākara (*SiTV*, ix. 1) have prescribed a successive repetition of the above rule. The method given in *LBh*, iv. 1 is approximate and simpler.

CHAPTER V

# ECLIPSES

## (1) ECLIPSE OF THE SUN

Introductory stanza:

1. Now shall be given the solar eclipse as taught by Ācārya Āryabhaṭa. At the beginning of that one should know the determination of the elements (to be used).

Mean distances in *yojanas* of the Sun and Moon:

2. (The mean distance) of the Sun is 459585 (*yojanas*); that of the Moon is 34377 (*yojanas*).

A rule for converting true distances known in minutes into true distances in *yojanas*:

3. These (severally) multiplied by their true distances in minutes (as determined before)[1] and divided by the radius (i.e., 3438 minutes) are known as the true distances in *yojanas* of the Sun and the Moon.[2]

That is,

Sun's true distance in *yojanas*

$$= \frac{\text{Sun's mean distance in } yojanas \times \text{Sun's true distance in minutes}}{\text{Radius}},$$

and Moon's true distance in *yojanas*

$$= \frac{\text{Moon's mean distance in } yojanas \times \text{Moon's true distance in minutes}}{\text{Radius}}$$

Diameters of the Earth, the Sun, and the Moon in terms of *yojanas*:

4. The diameter, in terms of *yojanas*, of the Earth has been stated by the learned to be 1050; of the Sun 4410; and of the Moon, 315.

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[1] *Vide supra*, Chapter IV, stanzas 9-12 and 19-20.

[2] This rule is found to occur also in *BrSpSi*, xxi. 31(ii); *ŚiDVṛ, I*, iv. 5(i); *LBh*, iv. 3; *SiŚe*, v. 4 (ii); *SiŚi, I*, v. 5(i); *TS*, iv. 10(ii)-11,

The following table gives the diameters and distances of the Sun and the Moon and their ratios according to Bhāskara I, Śrīpati, Bhāskara II, and also according to modern astronomers.

**Comparative table of diameters and distances of the Sun and Moon.**

| | Bhāskara I | Śrīpati | Bhāskara II | Modern, in miles |
|---|---|---|---|---|
| Sun's diameter in *yojanas* | 4410 | 6522 | 6522 | 86400 0 |
| Sun's distance in *yojanas* | 459585 | 684870 | 689377 | 92900000 |
| Ratio | ·009596 | ·009523 | ·009461 | ·0093 |
| Moon's diameter in *yojanas* | 315 | 480 | 480 | 2160 |
| Moon's distance in *yojanas* | 34377 | 51566 | 51566 | 238900 |
| Ratio | ·009163 | ·009308 | ·009308 | ·009 |

This table shows that, although the values of the diameters and mean distances of the Sun and the Moon given by different authorities differ, their ratios are practically the same. It may be pointed out that it is these ratios and not the diameters or distances that are used in the calculation of the eclipses—a fact which is partly responsible for the great accuracy attained by Hindu astronomers in the prediction of the eclipses.

## A rule for finding the angular diameters of the Sun and the Moon :

5. The diameters of the Sun and the Moon when (severally) multiplied by the radius and divided by their true distances in *yojanas* become the (angular) diameters in minutes.[1]

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[1] This rule is found also in *BrSpSi*, xxi. 34(ii) ; *ŚiDVṛ, I*, iv. 8; *SiŚe*, v. 6 ; and *SiŚi I*, v .7.

That is,

$$\text{Sun's diameter in minutes} = \frac{\text{Sun's diameter in } yojanas \times \text{R}}{\text{Sun's true distance in } yojanas},$$

$$\text{and Moon's diameter in minutes} = \frac{\text{Moon's diameter in } yojanas \times \text{R}}{\text{Moon's true distance in } yojanas}.$$

Formulae for the true (i.e., angular) diameters of the Sun, the Moon, and the shadow[1] in terms of the true daily motions of the Sun and the Moon :

6-7. Five-ninths of the (minutes of the Sun's true) daily motion and one-twenty-fifth of the (minutes of the Moon's true) daily motion (treated as minutes) respectively increased and diminished by the seconds equal to one-fourths of themselves are to be known as the true diameters of the Sun and Moon (respectively). One-tenth of (the minutes of) the moon's true daily motion (treated as minutes) plus one-sixteenth of the same treated as seconds is stated to be the (true) diameter of the shadow.[2]

That is to say,

(1) $\text{Sun's true diameter} = \frac{5}{9}(\text{Sun's true daily motion in minutes}) \text{ minutes}$

$+ \frac{5}{36}(\text{Sun's true daily motion in minutes}) \text{ seconds};$

(2) $\text{Moon's true diameter} = \frac{\text{Moon's true daily motion in minutes}}{25} \text{ minutes}$

$- \frac{\text{Moon's true daily motion in minutes}}{100} \text{ seconds};$

(3) True diameter of the shadow

$= \frac{\text{Moon's true daily motion in minutes}}{10} \text{ minutes}.$

$+ \frac{\text{Moon's true daily motion in minutes}}{16} \text{ seconds}.$

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[1] By the shadow is meant in this chapter the section of the cone of the Earth's shadow at the Moon's distance.

[2] Similar rules occur also in *BrSpSi*, iv. 6(i) ; *KK* (Sengupta's edition), iv. 2(i) ; *ŚiDVṛ, I*, iv. 9 ; *MSi*, v. 5(ii) ; *SiŚe*, v. 9; *SiŚi, I*, v. 8-9 ; *KPr*, v. 2.

The following is the *rationale* of the above formulae:

From stanza 5, we have

$$\text{Sun's true diameter} = \frac{\text{Sun's diameter in } yojanas \times R}{\text{Sun's true distance in } yojanas} \text{ minutes.}$$

But

$$\frac{R}{\text{Sun's true distance in } yojanas} = \frac{\text{Sun's true daily motion in minutes}}{\text{Sun's mean daily motion in } yojanas}.$$

Therefore,

$$\text{Sun's true diameter} = \frac{(\text{Sun's diameter in } yojanas) \times (\text{Sun's true daily motion in minutes})}{\text{Sun's mean daily motion in } yojanas} \text{ minutes.}$$

Now, according to Bhāskara I, a planet travels through 1,24,74,72,05,76,000 *yojanas* in 1,57,79,17,500 mean civil days, therefore the mean daily motion of a planet comes out to be 7905·8 *yojanas*. Hence,

$$\text{Sun's true diameter} = \frac{4410\,(\text{Sun's true daily motion in minutes})}{7905{\cdot}8} \text{ minutes.}$$

$$= \frac{5\,(\text{Sun's true daily motion in minutes})}{9} \text{ minutes} + \frac{161\,(\text{Sun's true daily motion in minutes}) \times 60}{7905{\cdot}8} \text{ seconds.}$$

$$= \frac{5\,(\text{Sun's true daily motion in minutes})}{9} \text{ minutes.} + \frac{5\,(\text{Sun's true daily motion in minutes})}{36} \text{ seconds.}$$

Similarly,

$$\text{Moon's true diameter} = \frac{315\,(\text{Moon's true daily motion in minutes})}{7905{\cdot}8} \text{ minutes.}$$

$$= \frac{\text{Moon's true daily motion in minutes}}{25} \text{ minutes.} - \frac{308\,(\text{Moon's true daily motion in minutes}) \times 60}{7905{\cdot}8 \times 25} \text{ seconds.}$$

$$= \frac{\text{Moon's true daily motion in minutes}}{25} \text{ minutes} - \frac{\text{Moon's true daily motion in minutes}}{100} \text{ seconds.}$$

The formula for the true diameter of the shadow given in the text depends entirely upon the true daily motion of the Moon whereas it ought to depend upon the true daily motions of the Sun and Moon both. The author obviously takes the mean diameter of the shadow to be that which corresponds to the mean distances of the Sun and the Moon and derives the value of the true diameter of the shadow therefrom by applying the usual process. The *rationale* seems to be as follows:

Mean diameter of the shadow

$$= \text{Earth's diameter} - \frac{(\text{Sun's diameter} - \text{Earth's diameter}) \times (\text{Moon's mean distance})}{\text{Sun's mean distance}}$$

$$= 1050 - \frac{(4410-1050) \times 34377}{459585}$$

$$= 1050 - \frac{3360 \times 34377}{459585}$$

$$= 1050 - 251{\cdot}3 = 798{\cdot}7 \textit{ yojanas.}$$

Therefore,

True diameter of the shadow

$$= \frac{798{\cdot}7 \times R}{\text{Sun's true distance in } \textit{yajanas}} \text{ minutes,}$$

$$= \frac{798{\cdot}7 \times (\text{Moon's true daily motion in minutes})}{\text{Moon's mean daily motion in } \textit{yojanas}} \text{ minutes.}$$

$$= \frac{798{\cdot}7 \times (\text{Moon's true daily motion in minutes})}{7905{\cdot}8} \text{ minutes}$$

$$= \frac{\text{Moon's true daily motion in minutes}}{10} \text{ minutes,}$$

$$+ \frac{\text{Moon's true daily motion in minutes}}{16} \text{ seconds.}$$

A rule for the determination of the (*sāyana*) longitude of the meridian-ecliptic point for the time of geocentric conjunction of the Sun and Moon:

8-11. Now is stated the method for (finding the longitude of) the meridian-ecliptic point. Those proficient in the (astronomical) science should know that the determination (of that) is made with the *asus* due to right ascension (i.e., with the times in *asus* of rising of the signs at the equator).

From the *asus* intervening between midday and the *tithyanta* ("the time of geocentric conjunction of the Sun and Moon") one should subtract in the forenoon the *asus* corresponding to the degrees traversed of the sign occupied by the Sun (at the *tithyanta*) and in the afternoon the *asus* corresponding to the degrees to be traversed. The degrees (traversed or to be traversed) should be (respectively) subtracted from or added to the longitude of the Sun (for the *tithyanta*). The complete signs determined with the help of the *asus* of the right ascensions of the signs and whatever (fraction of a sign) is obtained by proportion should also be (respectively) subtracted or added by those who know the true principles of the science of time. This (i.e., the longitude thus obtained) is the true (*sāyana*) longitude of the meridian-ecliptic point. So has come out of the mouth of the illustrious (Ācārya Ārya)bhaṭa.[1]

The five Rsines relating to the Sun and the Moon:

12. The orbits of the Sun and the Moon being different, the (five) Rsines for them are said to differ.[2] This (difference) is indicated by the words "*svadṛkkṣepa* etc." of the Master (Āryabhaṭa I).[3]

The five Rsines contemplated here are the so called *udayajyā*, *madhyajyā*, *dṛkkṣepajyā*, *dṛgjyā* and *dṛggatijyā*. Rules for finding these are gives in the next eleven stanzas.

A rule for finding the Sun's *udayajā*:

13. Multiply the Rsine of the *bāhu* due to the (*sāyana*) longitude of the rising point of the ecliptic by (the Rsine of) the (Sun's) greatest declination and then divide (the product) by (the Rsine of) the colatitude: the quotient is the Sun's true *udayajyā*.[4]

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[1] The Sun's longitude to be used in this rule must be *sāyana*.

[2] Lalla in his *Śiṣya-dhī-vṛddhida* takes for simplicity the five Rsines for the Moon to be the same as those for the Sun.

[3] *Vide Ā*, iv. 33.

[4] This rule occurs also in *ŚīDVṛ, I*, v. 4.

That is

$$\text{Sun's } udayajy\bar{a} = \frac{\text{Rsin } \lambda \times \text{Rsin } \epsilon}{\text{Rcos } \phi},$$

where $\lambda$ is the *sāyana* longitude of the rising point of the ecliptic, $\epsilon$ the greatest declination of the Sun, and $\phi$ the latitude of the place.[1]

The Sun's *udayajyā* is the Rsine of that part of the local horizon which lies between the east point and the rising point of the ecliptic. It is equal to the Rsine of the *agrā* of the rising point of the ecliptic and is, therefore, also known as *udayalagnāgrā* or simply *lagnāgrā*.

A rule for finding the Moon's *udayajyā*:

14-16(i). The Rsine of (the longitude of) the rising point of the ecliptic minus (the longitude of) the Moon's ascending node, multiplied by 15 and divided by 191, is the Rsine of the (Moon's) latitude corresponding to the rising point of the ecliptic. When the declination and (Moon's) latitude corresponding to the rising point of the ecliptic are of like direction, take their sum; in the contrary case, take their difference. The radius multiplied by the Rsine of the resulting arc (of the sum or difference) and then divided by (the Rsine of) the colatitude gives the the Moon's *udayajyā*.[2]

The Moon's *udayajyā* is the Rsine of that part of the local horizon which lies between the east point and the rising point of the Moon's orbit.

Rules for finding the *madhyajyās* of the Sun and the Moon:

16(ii)-18. Calculate the Rsine of the celestial latitude (of the Moon) from the longitude of the meridian-ecliptic point minus the longitude of the Moon's ascending node.

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[1] The *rationale* of this rule is similar to that of the Sun's *agrā*. See stanza 37 of Chapter III.

[2] This rule is approximate as the declination of the rising point of the Moon's orbit is not exactly equal to the sum or difference of the declination and Moon's latitude corresponding to the rising point of the ecliptic.

When the declination of the meridian-ecliptic point and the local latitude are of like direction[1], take their sum; in the contrary case, take their difference; (and determine the Rsine of that sum or difference). This is the Sun's *madhyajyā* which has the same direction as the above sum or difference.

In the case of the Moon, take the sum or difference of the local latitude, the declination (of the meridian-ecliptic point), and the (Moon's) latitude (corresponding to the meridian -ecliptic point) on the basis of likeness or unlikeness of direction; and then determine the Rsine of the resulting arc. This is the (Moon's) *madhyajyā*, which has the same direction as the resulting arc.[2]

The Sun's *madhyajyā* is the Rsine of the zenith distance of the meridian-ecliptic point. The Moon's *madhyajyā* is the Rsine of the zenith distance of the meridian point of the Moon's orbit.

A rule for the determination of the *dṛkkṣepajyās* of the Sun and the Moon :

19. Take the product of (the Sun's or Moon's) own *madhyajyā* and *udayajyā*, then divide (the product) by the radius, and then take the square (of the quotient). Subtract that from the square of the (own) *madhyajyā* : the square root of that (difference) is known as (the Sun's or Moon's) *dṛkkṣepajyā*.[3]

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[1] The direction of the local latitude is always south; the direction of the declination of the meridian-ecliptic point is north or south according as the meridian-ecliptic point is to the north or south of the equator.

[2] The rule for the Moon's *madhyajyā* is approximate, because the arcual distance between the points where the meridian intersects the ecliptic and the Moon's orbit is not equal to the Moon's latitude corresponding to the meridian-ecliptic point.

[3] This rule too is approximate and has been criticised by Brahmagupta. (See *BrSpSi*, xi. 29, 30). The *rationale* of the rule is as follows: Let Z be the zenith, M the meridian point of the ecliptic

The Sun's *dṛkkṣepajyā* is the Rsine of the zenith distance of that point of the ecliptic which is at the shortest distance from the zenith.[1] The Moon's *dṛkkṣepajyā* is the Rsine of the zenith distance of that point of the Moon's orbit which is at the shortest distance from the zenith.

A rule for finding the *dṛgjyās* (i.e., the Rsines of the zenith distances) of the Sun and the Moon :

20-22. Calculate the Rsine of the Sun's zenith distance (*dṛgjyā*) from the *nāḍīs* elapsed (since sunrise in the forenoon) or to elapse (before sunset in the afternoon) in accordance with the method stated before.[2] The method for (finding the Rsine of the zenith distance of) the Moon is now being described.

Take the sum or difference of the celestial latitude and declination of the Moon for the time of geocentric conjunction (of the Sun and Moon) according as they are of like or unlike direction. The Rsine of the resulting sum or difference is (the Rsine of) the Moon's (true) declination. From that calculate the day-radius, the earthsine, and the *asus* of the ascensional difference. With the help of these and the *nāḍīs* elapsed (since sunrise in the forenoon) or to elapse (before sunset in the afternoon) obtain the Rsine of the zenith distance. (This is the Rsine of the Moon's zenith distance).[3]

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(or Moon's orbit) and C the point of the ecliptic (or Moon's orbit) which is at the shortest distance from Z. Then in the triangle ZCM, Rsin ZM = *madhyajyā*, $\angle$ZCM = 90°, and Rsin $\angle$MZC = *udayajyā*. Therefore

Rsin (arc MC) = (*madhyajyā* × *udayajyā*)/R.

The final result is obtained by treating the triangle formed of the Rsines of the sides of the triangle ZCM as a plane right-angled triangle (which assumption is however incorrect).

The same rule occurs also in *ŚiDVṛ*, *I*, v. 5.

[1] The point of the ecliptic which is at the shortest distance from the zenith is called the nonagesimal or the central ecliptic point.

[2] *Vide supra*, chapter III, stanzas 18-25.

[3] This rule for the Rsine of the Moon's zenith distance is evidently approximate.

A rule for finding the *dṛggatijyās* of the Sun and the Moon:

23. Obtain the difference between the squares of the (Sun's as also of the Moon's) own *dṛgyā* and *dṛkkṣepajyā*, and then take their square-roots. These (square-roots) are the *dṛggatijyās* of the Sun and the Moon.[1]

The Sun's *dṛggatijyā* is the distance of the zenith from the plane of the secondary to the ecliptic passing through the Sun. The Moon's *dṛggatijyā* is the distance of the zenith from the plane of the secondary to the Moon's orbit passing through the Moon.

In later astronomical literature, the *dṛggatijyā* is used to mean the Rsine of the altitude of the central ecliptic point (i. e., the point of the ecliptic nearest from the zenith); and the distance of the zenith from the plane of the secondary to the ecliptic is denoted by the term *dṛṅnatijyā*.

The *rationale* of the above rule is as follows: In Fig. 18,[2] CS is the ecliptic and K its pole; S is the Sun and Z the zenith; KZC and KS are secondaries to the ecliptic; and ZA is perpendicular to KS. Since the arcs ZC and ZA are perpendicular to CS and AS respectively, therefore

$$(\text{Rsin ZA})^2 = (\text{Rsin ZS})^2 - (\text{Rsin ZC})^2,$$

i.e., (Sun's *dṛggatijyā*)$^2$ = (Sun's *dṛgjyā*)$^2$ — (Sun's *dṛkkṣepajyā*)$^2$. Similarly, in the case of the Moon.

A rule for finding the time of apparent conjunction of the Sun and Moon:

24-27. Severally multiply the own *dṛggatijyās* (of the Sun and the Moon) by the Earth's semi-diameter and divide the products by the respective true distances in *yojanas*. The quotients (thus obtained) are known as the *lambanas* (of the Sun and the Moon) in terms of minutes (of arc), etc.

Multiply their difference by 60 and divide that by the difference between the true daily motions of the Sun and the Moon. Thus are obtained the *ghaṭīs* etc. (of the *lambana*). In the forenoon, subtract them from, and in the afternoon, add

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[1] This rule occurs also in *SiDVṛ*, *I*, v. 6(i).

[2] See *infra*, p. 165.

them to the time of geocentric conjunction of the Sun and Moon. (Then is obtained the first approximation to the time of apparent conjunction).

The *lambana* computed for the middle of the day is subtracted from the time of geocentric conjunction when the Moon's *udayajyā* is north and added when south.

Repeat this process until the nearest approximation (to the *lambana* for the time of apparent conjunction) is arrived at.[1]

The corresponding displacements should be given by the learned to (the longitudes of) the Sun and the Moon, as in the case of the *tithi* (i.e., the time of conjunction of the Sun and the Moon).[2]

The term *lambana* is the technical term for "parallax in longitude". When used alone in connection with a solar eclipse it generally stands for the difference between the parallaxes in longitude of the Sun and the Moon.

The above stanzas aim at finding out the time of apparent conjunction of the Sun and Moon. This involves a knowledge of the *lambana* for that time. For,

time of apparent conjunction = time of geocentric conjunction
$\pm$ *lambana* in time for the time of apparent conjunction,

where + or — sign is taken according as the Sun and the Moon at the time of apparent conjunction lie to the west or east of the central ecliptic point.

The *lambana* for the time of apparent conjunction depends on the time of apparent conjunction itself. But as the time of apparent conjunction is unknown, the corresponding *lambana* cannot be obtained directly and recourse is taken to the method of successive approximations stated in the text.

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[1] The literal translation would run as follows: Repeat this process until the time of apparent conjunction is fixed.

[2] What is meant is that after the first approximation to the time of apparent conjunction is obtained, the corresponding longitudes of the Sun and the Moon should be calculated and the process repeated.

To begin with, the time of geocentric conjunction is taken as the first approximation to the time of apparent conjunction and the corresponding *lambana* is obtained by the following formula :

$$lambana = \frac{\text{Moon's } dṛggatijyā \times \text{Earth's semi-diameter}}{\text{Moon's true distance in } yojanas} - \frac{\text{Sun's } dṛggatijyā \times \text{Earth's semi-diameter}}{\text{Sun's true distance in } yojanas} \text{ minutes.}$$

This formula may be derived as follows :

Consider Fig.18. CS is the ecliptic, C and S being the central ecliptic point and the Sun at the time of geocentric conjunction (treated as the time of apparent conjunction). K is the pole of the ecliptic and Z the zenith. S′ is the position of the Sun as observed from the local place. ZA and S′B are perpendiculars on the secondary to the ecliptic passing through S′ (i.e., on KS); S′D is perpendicular to the ecliptic.

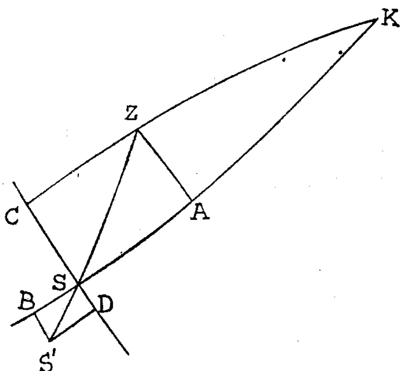



Fig. 18

In the triangle S′DS right-angled at D, SS′ denotes the Sun's parallax in zenith distance and SD denotes the Sun's parallax in longitude (*lambana*).

From the triangles SBS′ and SAZ, right-angled at B and A respectively, we have

$$\text{Rsin (arc BS}') = \frac{\text{Rsin (arc AZ)} \times \text{Rsin (arc SS}')}{\text{Rsin (arc ZS)}}.$$

But Rsin (arc BS′) = BS′ or SD approximately. Therefore,

$$\text{Sun's } lambana = \frac{(\text{Sun's } dṛggatijyā) \times \text{Rsin (arc SS}')}{\text{Rsin (arc ZS)}} \text{ approx.}$$

But

$$\text{Rsin (arc SS}') = \frac{\text{Earth's semi-diameter} \times \text{Rsin (arc ZS)}}{\text{Sun's true distance in } yojanas}.$$

Hence

$$\text{Sun's } lambana = \frac{\text{Sun's } dṛggatijyā \times \text{Earth's semi-diameter}}{\text{Sun's true distance in } yojanas}. \quad \text{... (1)}$$

Similarly,

$$\text{Moon's } lambana = \frac{\text{Moon's } d\d{r}ggatijy\bar{a} \times \text{Earth's semi-diameter}}{\text{Moon's true distance in } yojanas}. \quad \ldots (2)$$

Subtracting (1) from (2), we obtain the required formula.

The *lambana* obtained by the above formula is in terms of minutes of arc. When this is multiplied by 60 and divided by the difference between the true daily motions of the Sun and the Moon, it is reduced to the corresponding *ghaṭīs*. The *lambana* in *ghaṭīs* according to the text is to be subtracted from or added to the time of geocentric conjunction according as it occurs in the forenoon or afternoon. In fact, subtraction or addition should be made according as the conjunction occurs to the east or to the west of the central ecliptic point. The law of addition and subtraction given in the text is, however, more convenient in practice.

The rule in stanza 26 shows that the author was aware that at noon the *lambana* was different from zero. Still the rule prescribed for the application of that *lambana* in that stanza shows that the author did not know the correct law for the addition or subtraction of that *lambana*.[1]

The application of the *lambana* for the time of apparent conjunction having been thus made to the time of geocentric conjunction, we obtain the second approximation to the time of apparent conjunction. The Sun and the Moon are then calculated for that time and the method is repeated again and again until the nearest approximation to the time of apparent conjunction is obtained.

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[1] The commentators have, however, tried to interpret the stanza as conveying the desired meening. For example, Parameśvara writes : "The word *indu* here stands for the *madhyajyā*. Therefore, subtraction is to be made when the *madhyajyā* and the *udayajyā* are of like direction. When they are of unlike directions, addition is to be made. This is what has been stated here". The word *indu* means "Moon" and it cannot be interpreted to mean "*madhyajyā*". There is no scope for such a meaning. Moreover, Parameśvara says that subtraction or addition is to be made according as the *madhyajyā* and *udayajyā* are of like or unlike directions. In fact, there is no reference to any directions, like or unlike. The words used are *udak* and *dakṣiṇe* which mean "in the north" and "in the south" respectively and not "like direction" and "unlike directions" as Parameśvara has supposed.

A rule for finding the true *nati* :

28-32. Multiply the *dṛkkṣepajyās* (of the Sun and the Moon), obtained by the method of successive approximations, (severally) by the Earth's semi-diameter, and divide (the resulting products) by the true distances in *yojanas* (of the Sun and the Moon respectively): the quotients are in minutes of arc (the parallaxes in latitude of the Sun and the Moon). Take their difference, provided that the *madhyajyās* of the Sun and the Moon are of like direction ; in the contrary case, take their sum : thus are obtained the minutes of the *avanati* (or *nati*). (As regards the direction of the *nati*) take the direction of the Moon's (*madhyajyā*).

Multiply the Rsine of the longitude of the Moon minus the longitude of the Moon's ascending node by 270, and then divide that product by the Moon's true distance in minutes. Thus is obtained the true celestial latitude of the Moon. This increased by that (*nati*) (provided the two are of like direction) is the true *nati*. In case they are of unlike directions, take their difference. The difference is then called the (true) *nati*.

Thus is obtained the true *avanati* (or true *nati*) for the middle of the eclipse as determined from the *dṛkkṣepa* and the true latitude of the Sun and the Moon for the time of apparent conjunction (literally, the time of geocentric conjunction corrected for the *lambana*-difference).

The term *nati* or *avanati* means "parallax in latitude". When used alone in connection with a solar eclipse, it denotes the difference betweeu the parallaxes in latitude of the Sun and the Moon. The true *nati* is the Moon's latitude corrected for the *nati* (i.e., Moon's apparent latitude). It denotes the arcual distance of the Moon from the Sun's apparent orbit due to parallax.

The formula given for the *nati* for the time of apparent conjunction of the Sun and the moon is

$$nati = \frac{\text{Moon's } d\d{r}kk\d{s}epajy\bar{a} \times \text{Earth's semi-diameter}}{\text{Moon's true distance in } yojanas} - \frac{\text{Sun's } d\d{r}kk\d{s}epajy\bar{a} \times \text{Earth's semi-diameter}}{\text{Sun's true distance in } yojanas}.$$

The *rationale* of this formula is as follows :

Refer to the previous figure. From the triangles S′DS and ZCS, right-angled at D and C respectively, we have

$$\text{Rsin (arc S}'\text{D) or arc S}'\text{D} = \frac{\text{Rsin (arc ZC)} \times \text{Rsin (arc SS}'\text{)}}{\text{Rsin (arc ZS)}}.$$

But

$$\text{Rsin (arc SS}'\text{)} = \frac{\text{Earth's semi-diameter} \times \text{Rsin (arc ZS)}}{\text{Sun's true distance in } yojanas}.$$

Therefore,

$$\text{Sun's } nati = \frac{\text{Rsin (arc ZC)} \times \text{Earth's semi-diameter}}{\text{Sun's true distance in } yojanas}$$

$$= \frac{\text{Sun's } d\d{r}kk\d{s}epajy\bar{a} \times \text{Earth's semi-diameter}}{\text{Sun's true distance in } yojanas} \quad (1)$$

Similarly,

$$\text{Moon's } nati = \frac{\text{Moon's } d\d{r}kk\d{s}epajy\bar{a} \times \text{Earth's semi-diameter}}{\text{Moon's true distance in } yojanas}. \quad (2)$$

Subtracting (1) from (2), we get the required formula.

Like the *lambana* for the time of apparent conjunction, the *nati* too for that time is determined by the method of successive approximations.

On the possibility of a solar eclipse :

33. An eclipse of the Sun will not occur if the (true) *nati* is equal to (or greater than) half the sum of the diameters of the Sun and the Moon. It is possible when it (i.e., the true *nati*) is less (than that).

A rule for the determination of the *sparśa-sthityardha and mokṣa-sthityardha* :

34-39. Multiply the square root of the difference detween the squares of half the sum of the diameters of the Sun and Moon and of the (true) *nati* by 60 and then divide (the product) by the motion-difference (of the Sun and the Moon) : thus are obtained the *ghaṭīs* of the *sthityardha*. By these *ghaṭīs*

diminish and increase the time of apparent conjunction as obtained by the method of successive approximations. Then are obtained the (approximate) times for the first and last contacts respectively. Proceeding with them, calculate the (ten) Rsines (for the Sun and the Moon), etc., (and obtain the nearest approximations to the *lambanas* for the times of the first and last contacts). Always add, in the case of a solar eclipse, the *nāḍīs* of the difference between the *lambanas* for the first contact and the apparent conjunction to the *sthityardha*: (the result is the *sparśa-sthityardha*). Also add the (*nāḍīs* of the difference between the) *lambanas* for the apparent conjunction and the end of the eclipse to the *sthityardha*: the result is the *mokṣa-sthityardha*. The *sthityardhas* thus obtained are very accurate: I say this raising my hands aloft (i.e., with firm determination).

When the first contact and the apparent conjunction occur in different halves (eastern and western) of the celestial sphere, then the entire *lambana* (in *nāḍīs*) for the time of the first contact is added to the *sthityardha*. Similarly, when the last contact and the apparent conjunction occur in different halves of the celestial sphere, the entire *lambana* (in *nāḍīs*) for the time of the last contact is always added to the *sthityardha*. The same procedure is also adopted when the apparent conjunction occurs at noon.

The term *sthityardha* means "half the duration (of an eclipse)", The *sparśa-sthityardha* is the interval of time between the first contact and the apparent conjunction. The *mokṣa-sthityardha* is the time-interval between the apparent conjunction and the last contact.

A rule for the determination of the *vimardārdha*:

40. The *nāḍīs* of the *vimardārdha* are to be determined from the square root of the difference between the squares of (i) the difference between the semi-diameters of the eclipsed and eclipsing bodies and (ii) the Moon's latitude (corrected for the *nati*).

The term *vimardārdha* means "half the duration of the totality of an eclipse", i.e., the time-interval between the immersion and the apparent conjunction or between the apparent conjunction and the emersion. The time-interval between the immersion and the apparent conjunction is called the *sparśa-vimardārdha* and that between the apparent conjunction and the emersion is called the *mokṣa-vimardārdha.*

The above stanza gives the method for finding the first approximation to the *vimardārdha* in minutes of arc. The corresponding *nāḍīs* are obtained by multiplying that by 60 and dividing by the difference between the true daily motions of the Sun and the Moon. The nearest approximations to the *sparśa-* and *mokṣa-vimardārdhas* are obtained as in the case of the *sthityardhas.*

A rule for knowing the time of actual visibility of the first contact in the case of a solar eclipse :

41. On account of the brightness of the Sun, the time of (actual visibility of) the first contact (in the case of a solar eclipse) is the (computed) time of the first contact plus the time corresponding to the minutes of arc amounting to one-eighth of the Sun's diameter.

Āryabhaṭa I says: "When the moon eclipses the Sun, even though one-eighth part of the Sun is eclipsed this is not perceptible because of the brightness of the Sun and the transparency of the Moon's circumference."[1]

A rule for finding the magnitude and direction of the *akṣa-valana* :

42-44. Multiply the Rversed-sine of the *asus* intervening between midday and the *tithi* (i.e., the time of the first contact, the middle of the eclipse, or of the last contact) by (the Rsine of) the (local) latitude and divide that (product) by the radius. Reduce the resulting Rsine to the corresponding arc (called *akṣa-valana*) and determine its direction.

When the above *asus* exceed (those corresponding to) a quadrant, add the Rsine of the excess to the radius and operate as before ; and then find the direction.

[1] Ā, iv. 47.

The direction (of the *akṣa-valana*) for the middle of the ecliptic is the same as that for the first contact.

In the forenoon, the directions (of the *akṣa-valana*) in the eastern and western halves of the disc (of the eclipsed body) are north and south respectively. To the west of the sky (i.e., in the afternoon), the *akṣa-valana* is always of the contrary direction.[1]

The great circle of the celestial sphere which has the centre of the eclipsed body as one of its poles is called the horizon of the eclipsed body. Suppose that the prime vertical, the equator, and the ecliptic intersect the horizon of the eclipsed body[2] at the points $E_1$, $T_1$, and $Y_1$ respectively towards the east of the eclipsed body. Then the point $E_1$ is called the east point of the horizon of the eclipsed body; the arc $E_1T_1$ (which denotes the deflection of the equator from the prime vertical on the horizon of the eclipsed body) is called the *akṣa-valana*; and the arc $T_1Y_1$ (which denotes the deflection of the ecliptic from the equator along the same circle) is called the *ayana-valana*.

The formula for the *akṣa-valana* stated in the text is

$$\text{Rsin}\,(\textit{akṣa-valana}) = \frac{\text{Rversin}\, H \times \text{Rsin}\, \phi}{\text{R}},$$

where $H$ denotes the hour angle (*nata-kāla*) and $\phi$ the local latitude.

This formula is based on inference. Early Hindu astronomers noted that when the eclipsed body was at the intersection of the meridian and the equator, the Rversed-sine of the hour angle was zero and the Rsine of the *akṣa-valana* was also zero; and that with the increase of the Rversed-sine of the hour angle the Rsine of the *akṣa-valana* also increased; and further that when the eclipsed body was at the intersection of the horizon and the equator, the Rversed-sine of the hour angle was equal to its maximum value R and the Rsine of the *akṣa-valana* was also maximum and equal to the Rsine of the latitude. They, therefore, supposed that the Rsine of the *akṣa-valana* varied as the Rversed-sine of the hour angle, and to obtain the Rsine of the *akṣa-valana* for the desired time they made use of the

[1] The same rule is found also in *ŚiDVṛ*, *I*, iv. 23 and *SiŚe*, v. 18.

[2] By the eclipsed body here is meant the position of the eclipsed body on the ecliptic.

proportion : When the Rversed-sine of the hour angle amounts to R, the Rsine of the *akṣa-valana* equals the Rsine of the latitude, what then would be the value of the Rsine of the *akṣa-valana* corresponding to the Rversed-sine of the desired hour angle ? Hence the above formula.

The above formula can be easily seen to be incorrect. It was first modified by Brahmagupta, who replaced Rversin $H$ by Rsin $H$.[1] Better and accurate formulae were given by Bhāskara II.[2]

The rules for the direction of the *akṣa-valana* can be seen to be true by means of a diagram.

A rule for the determination of the magnitude and direction of the *ayana-valana* :

45. The (Sun's) declination determined from the Rversed-sine of the longitude of the Sun or Moon as increased by three signs (treated as the Rsine of the *bhuja*) (is the *ayana-valana*). Its direction in the eastern half (of the disc of the eclipsed body) is the same as that of the *ayana* (of the Sun or Moon);[3] in the other half, it is contrary to that.[4]

That is,

$$\text{Rsin}\,(\textit{ayana-valana}) = \frac{\text{Rsin}\ \epsilon \times \text{Rversin}\ (\lambda+90^\circ)}{\text{R}},$$

where $\epsilon$ denotes the obliquity of the ecliptic and $\lambda$ the *sāyana* longitude of the eclipsed body (the Sun or Moon).

This formula also is based on inference. The proportion used is the following : "When Rversin $(\lambda+90^\circ)$ is equal to R, the Rsine of the *ayana-valana* is equal to the Rsine of the obliquity of the ecliptic, what then would be the Rsine of the *ayana-valana* corresponding to the desired value of the Rversed-sine ?"

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[1] See *BrSpSi*, iv. 16.

[2] See *SiŚi*, *I*, v. 20-21(i); *II*, viii. 68; and *II*, viii. 66(ii)-67.

[3] The *ayana* of a planet is north or south according as it is in the half-orbit beginning with the (*sāyana*) sign Capricorn or in that beginning with the (*sāyana*) sign Cancer.

[4] This rule occurs also in *ŚiDVṛ*, *I*, iv. 25 and *SiŚe*, v. 20.

This formula also is incorrect. It was modified by Brahmagupta,[1] who replaced Rversin $(\lambda+90°)$ in the formula by Rsin $(\lambda+90°)$. An accurate expression for the *ayana-valana* was given by Bhāskara II (1150 A. D.).[2]

A rule for finding the value of the resultant *valana* (*spaṣṭa-valana*) for the circle drawn with half the sum of the diameters of the eclipsed and eclipsing bodies as radius:

46-47. When they (i.e., the *akṣa-valana* and the *ayana-valana*) are of unlike directions, take the difference of their arcs; in the contrary case, take their sum.[3] Multiply the Rsine of that (sum or difference) by half the sum of the diameters of the eclipsed and eclipsing bodies and divide (the product) by the radius. Add whatever is thus obtained to the (Moon's true) *nati*, provided that they are of like directions; in the contrary case, take their difference: the resulting sum or difference is the *valana*.

The sum or difference of the *akṣa-valana* and the *ayana-valana* according as they are of like or unlike directions gives the so called *spaṣṭa-valana*, i.e., the amount of deflection of the ecliptic from the prime vertical on the horizon of the eclipsed body. When the Rsine of that is multiplied by half the sum of the diameters of the eclipsed and eclipsing bodies and the product divided by the radius, we get the corresponding deflection on the circumference of the circle drawn with half the sum of the diameters of eclipsed and eclipsing bodies as radius. The sum or difference of this and the Moon's true *nati* according as the two are of like or unlike directions gives the distance of the centre of the eclipsing body from the east-west line passing through the centre of the eclipsed body. So has been assumed in the above rule.

The direction in the rule for adding or taking the difference of the reduced *spaṣṭa-valana* and the Moon's true *nati* is wrong. The two quantities should be kept separately and laid off properly one after the other (in the projected figure).

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[1] See *BrSpSi*, iv. 17.

[2] See *SiŚi, I*, v. 21(ii)-22(i).

[3] This rule occurs also in *BrSpSi*, iv. 18 (i) and *ŚiDVṛ, I*, iv. 26.

**The next twenty stanzas ralate to the projection (i.e., graphical representation) of an eclipse.**

A method for ascertaining the centre of the eclipsing body for the times of the first and last contacts (called the *sparśa-bindu* and the *mokṣa-bindu* respectively) :

48-53. By means of a pair of compasses, whose smooth and large body is graduated with *aṅgulas* and subdivisions thereof and which is embellished by the pointed end of a smoothened chalk-stick placed into its mouth, construct on the ground a circle with half the measure, in *aṅgulas*, of the eclipsed body as radius, and another (concentric circle) with half the sum of the diameters of the eclipsed and eclipsing bodies as radius. (Through the common centre) then draw the east-west line and, with the help of a fish-figure, the north-south line. From the centre then lay off the *valana* (for the first or last contact) towards the north or south (according to its direction) ; draw a fish-figure there ; and (through its head and tail) carefully[1] draw a line to meet the outer circle. At the meeting point of the outer circle and that line set a point. (This is the centre of the eclipsing body for the time of the first or last contact). From that point stretch out a line to reach the centre. Where this line is seen to intersect the circumference of the eclipsed body, lies the point of contact or separation of the Sun's disc.

One minute of arc should be taken as equivalent to one half of an *aṅgula* or as it appears in the sky.

A method for determining the centre of the eclipsing body for the middle of the (solar) eclipse (called the *madhya-bindu*) :

54-57. The *valana* for the middle of the eclipse is taken

[1] The word "carefully" indicates that when the *valana* corresponds to the first contact, the line should be drawn towards the west or east according as the eclipse is solar or lunar ; but when the *valana* corresponds to the last contact, the line should be drawn in the contrary direction.

without the addition or subtraction of the *nati*. When that and the *nati* are of like direction, the (*madhya*)*valana* should be laid off towards the east; when they are of unlike directions, it is stretched out from the centre towards the west. With the help of a fish-figure (drawn about the point thus obtained), a line should then be drawn in the direction of the *nati*. From the meeting point of that with the outer circle, the intelligent should then draw a line to reach the centre (of the circle).[1] The *nati* should then be laid off from the centre along that line. At the end of that lies the centre of the eclipsing body at the middle of the eclipse (i.e., the *madhya-bindu*). The two points (already marked) are the centres of the eclipsing body for the times of the first and last contacts (i.e., the *sparśa-bindu* and (*mokṣa-bindu*).

When the *nati* (for the middle of the eclipse) is of south direction, it should be laid off towards the south; when it is of north direction, it is laid off towards the north.

Points of difference of procedure in the case of a lunar eclipse:

58. This (i.e., the previous rule) is the method for the middle of the eclipse in the case of a solar eclipse. In the case of a lunar eclipse, the points of the first contact, the middle of the eclipse, and the last contact should be clearly indicated reversely.

That is, in the case of a lunar eclipse, the following procedure should be adopted: To begin with, the *madhya-valana* should be laid off towards the west or east, according as the *madhya-valana* and the *nati* are of like or unlike directions. With the help of a fish-figure drawn about the point thus obtained a line should then be drawn through that point in the direction contrary to the direction of the Moon's latitude. From the meeting point of that line with the outer circle a line should then be drawn to reach

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[1] This line is prependicular to the ecliptic at the time of the middle of the eclipse.

the centre of the circle. The Moon's latitude for the middle of the eclipse should then be laid off from the centre along that line.

Construction of the phase of the eclipse for the time of the middle of the eclipse :

59-60. Quickly cut off the eclipsed body by means of a pair of compasses (one leg of) which is placed at the *madhya-bindu* and (the other leg of) which is streched out by half the specified true measure of the eclipsing body. The portion thus cut off (in case the eclipse is partial), or the entire disc of the eclipsed body drawn (*likhitam*) on the projection (in case the eclipse is total)—all of that is clearly seen (in the sky) in that way at the time of the middle of the eclipse.

By the world *likhita*, says Parameśvara, is meant a total eclipse, or, in case the Moon's latitude is zero and the disc of the eclipsed body is larger, an annular eclipse.

Construction of the path of the eclipsing body:

61. Draw (an arc of) a circle passing through the three points set down above with the help of two fish-figures : this is the path of the eclipsing body. The phase of the eclipse for the given time is ascertained [by determining the position of the eclipsing body on that path and drawing its disc with its centre) there.[1]

A method for calculating the phase of the eclipse for the given time :

62-63. Multiply the difference between the (true) daily motions of the Sun and the Moon by the *sthityardha-ghaṭīs*[2] minus the given time (*iṣṭakāla*) and divide the product by sixty. Add the square of the quotient to the square of the Moon's *nati* (corrected latitude) (for the given time) and then take the square root of that (sum). This (square root) is (the length of)

[1] This rule occurs also in *ŚiDVṛ, I*, iv. 34.

[2] That is, *ghaṭīs* corresponding to the *sthityardha*.

the needle joining the centres of the eclipsed and eclipsing bodies at the given time in the case of solar and lunar eclipses. (Subtract that from half the sum of the diameters of the eclipsed and eclipsing bodies). The remainder is the phase of the eclipse for the given time.[1]

By the given time is meant the time elapsed since the first contact or the time to elapse before the last contact.

Construction of the phase of an eclipse for the given time :

64-65. Stretch out a fine bamboo needle (equal in length to that joining the centres of the eclipsed and eclipsing bodies at the given time) obliquely from the centre in such a way that its end may fall on the so called path of the eclipsing body. Taking the centre at that point, cut off the eclipsed body by means of a circle drawn with half the diameter of the eclipsing body as radius. As much portion is thus cut off, so much of the eclipsed body is seen to be eclipsed (in the sky).

Construction of the phase of a (solar) eclipse for the time of immersion or emersion:

66-67. The *sthityardha* in terms of minutes of arc minus the minutes of the *vimardārdha* is the means for projecting the phase of the eclipse for that time (i.e., immersion or emersion). The Sun's disc should be cut off with the help of that (i.e., that should be laid off from the *sparśa* or *mokṣa bindu* along the path of the eclipsing body towards the centre and the point thus obtained should be treated as the centre of the eclipsing body for that time). The disc of the Sun should be cut off by means of a pair of compasses. The seizure (of the Sun) occurs on the western side of the disc and the separation on the eastern side.

The remaining chapter deals with the lunar eclipse.

[1] This rule is found also in *BrSpSi*, iv. 11-12; *ŚiDVṛ, I*, iv. 19-20; *SiŚe*, v. 14.

## (2) ECLIPSE OF THE MOON

Points of difference of procedure in the case of a lunar eclipse :

68-70. Similarly, in the case of the Moon, which is the mirror for the face of the directions and exhibits (or bears) all excellent phases and whose round body looks like the face of a damsel, too, the (ten) Rsines should be found out. The points of difference (in the procedure) are being stated.

The (five) Rsines relating to the shadow should be determined as arising from the Sun's orbit. (In place of the Sun's distance) the Moon's distance is stated to be the divisor. The *lambana*, determined as in the case of the Sun, should be added or subtracted reversely.

Use of parallax in a lunar eclipse prescribed in the above stanzas is obviously wrong. Parameśvara comments: "Thus in the case of a lunar eclipse also, the use of parallax is stated here. This, say the proficients in Spherics, is improper".

It must be mentioned that the application of parallax in the case of a lunar eclipse has not been prescribed in any other work on Hindu astronomy, not even in the smaller work of the present author.

A rule for the determination of the diameter of the shadow, i.e., the diameter of the section of the Earth's shadow where the Moon crosses it :

71-73. Multiply the Sun's (true) distance in *yojanas* by the Earth's diameter and divide by the difference of their diameters: thus is obtained the length of the Earth's shadow. Or, multiply the Sun's (true) distance in *yojanas* by 5 and divide by 16: the result is called the length of the Earth's shadow,

From that (length of the Earth's shadow) subtract the Moon's distance. Multiply the remainder by the Earth's diameter and divide (the product) by the length of the (Earth's) shadow. Multiply the resulting quotient by the radius and divide (the product) by the Moon's distance (in *yojanas*): this is (the diameter of) the shadow (in minutes of arc).

That is,
the diameter of the shadow

$$= \frac{\{\text{length of Earth's shadow} - \text{Moon's distance}\} \times \text{Earth's diameter}}{\text{length of Earth's shadow}},$$

where

$$\text{length of Earth's shadow} = \frac{\text{Sun's distance} \times \text{Earth's diameter}}{\text{Sun's diameter} - \text{Earth's diameter}}.$$

This result is approximate and is the same as that given by Āryabhaṭa I.[1] It is usually derived by the following method (called "the lamp and shadow method"):

Consider Fig. 19. S is the centre of the Sun and E that of the Earth. SA and EB are drawn perpendicular to SE and denote the semi-diameters of the Sun and the Earth respectively. BL is parallel to ES. O is the point where SE and AB produced meet each other.

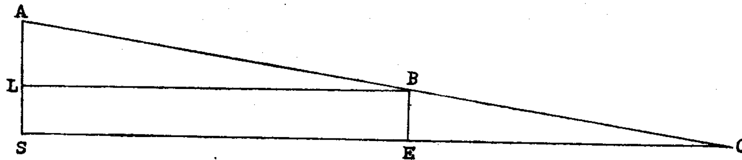



Fig. 19

Hindu astronomers compare SA with a lamp-post, EB with a gnomon, and EO with the length of the shadow cast by the gnomon due to the light of the lamp. Consequently, they call EO "the length of the shadow".

The triangles BEO and ALB are similar, therefore

$$\frac{EO}{BE} = \frac{BL}{LA}$$

$$= \frac{SE}{SA - EB}.$$

Therefore

$$EO = \frac{SE \times BE}{SA - EB} = \frac{SE \times 2BE}{2SA - 2EB}$$

i.e.,

$$\text{length of Earth's shadow} = \frac{\text{Sun's distance} \times \text{Earth's diameter}}{\text{Sun's diameter} - \text{Earth's diameter}}.$$

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[1] See *Ā*, iv. 39-40. This rule is found also in *BrSpSi*, xxiii. 8-9; and *ŚiDVṛ*, *I*, iv. 6 (ii)-7.

Now consider Fig. 20. AC and BD are the diameters of the Sun and the Earth. BOD is the shadow-cone[1], O its vertex. S and E are the centres of the Sun and the Earth. M is the point where the Moon crosses the shadow cone. MN is perpendicular to the axis of the shadow-

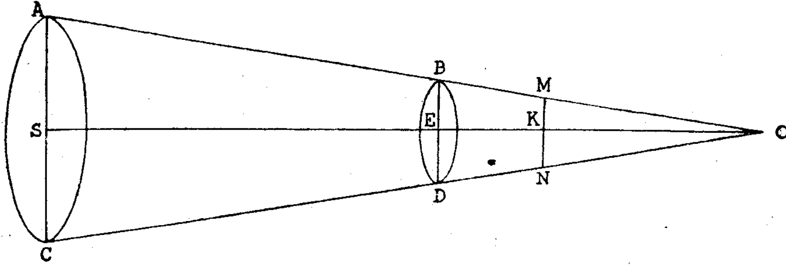



Fig. 20

cone and denotes the diameter of the section of the shadow cone where the Moon crosses it. It is called the diameter of the shadow.

The triangles MON and BOD are similar, so that

$$\frac{MN}{KO}=\frac{BD}{EO}.$$

Therefore,

$$MN=\frac{KO \times BD}{EO}$$

$$=\frac{(EO - EK)\times BD}{EO}$$

$$=\frac{(EO - EM)\times BD}{EO} \text{ approx.}$$

i.e., the diameter of the shadow

$$=\frac{\{\text{length of Earth's shadow} - \text{Moon's distance}\} \times \text{Earth's diameter}}{\text{length of Earth's shadow}}$$

The approximations made in the above procedure are obvious.[2]

The diameter thus obtained is in *yojanas*. To reduce it to minutes of arc we have to multiply it by the radius (i.e., 3438′) and divide by the Moon's distance in *yojanas*.

[1] Approximately.

[2] The formula for the diameter of the shadow stated above was modified and refined by Munīśvara (1646 A. D.) and Kamalākara (1658 A. D.). The latter astronomer gave an accurate expression for the diameter of the shadow (in *SiTV*, ix. 29-33).

Views of other astronomers regarding the calculation of a lunar eclipse:

74. Others give instruction in the lunar eclipse without the use of the ten Rsines, because it causes little difference in the result (and is simpler). There (i.e., in the rule stated by them) the *sparśa-* and *mokṣa-sthityardhas* arising from (the Moon's latitude for) the time of opposition of the Sun and Moon (lit. middle of the eclipse) should be operated upon by the method of successive approximations.

Details of the process of successive approximations referred to above:

75-76. Multiply the (true) daily motion (of the Moon) by the time (in *ghaṭīs*) of the *sthityardha* and divide the product by 60. Subtract the quotient from or add that to the Moon's (true) longitude for the time of opposition (of the Sun and Moon), according as it is the first or last contact. From that find out the Moon's latitude; and therefrom (again) calculate the *sthityardha*. (In this way repeat the above process again and again until two successive approximations agree). This is the process of successive approximations. Similar again is the process of (determining) the (*sparśa-* and *mokṣa-*) *vimardārdhas*.[1]

A rule relating to the direction of the Moon's latitude to be taken in the projection of a lunar eclipse:

77. While projecting an eclipse (of the Moon), the best amongst the learned should take the direction of the Moon's latitude to be north when it is south, and south when it is north.

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[1] For details see our notes on *LBh*, iv. 10-12. The rule stated here is found also in *BrSpSi*, iv. 8-9 ; *ŚiDVṛ*, *I*, iv. 14-16 ; *SiŚe*, v. 12-13; *SiŚi*, *I*, v. 12-13.

Concluding stanza in praise of the methods for calculating and projecting an eclipse that have been stated above :

78. This procedure regarding the Sun, the Moon, and the shadow, which has come down (to us) by tradition, has been stated here having cast off pride and jealousy. A learned person who acquires a mastery of this (procedure) shall become a (proficient) astronomer well versed in all astronomical methods.

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CHAPTER VI

# RISING, SETTING AND CONJUNCTION OF PLANETS.

A rule relating to the visibility-correction known as *akṣa-dṛkkarma* :

1-2(i). Multiply the Moon's latitude for the desired time by the Rsine of latitude of the local place, and divide (the product) by the Rsine of the colatitude; whatever is thus obtained, say the learned, should be subtracted (from the Moon's longitude) in the case of rising of the Moon (i.e., in the eastern hemisphere) and added (to the Moon's longitude) in the case of setting of the Moon (i.e., in the western hemisphere), provided that the Moon is to the north of the ecliptic (i.e., if the Moon's latitude is north). When the Moon is to the south of the ecliptic, the law (of addition and subtraction) is the reverse.[1]

The correction stated in the first three stanzas of this chapter is called "the visibility-correction (*dṛk-karma*)". When we apply this correction to the true longitude of the Moon, we obtain the longitude of that point of the ecliptic which rises or sets with the apparent Moon.

The visibility-correction is generally broken up into two components : (1) the visibility-correction due to the latitude of the local place (*akṣa-dṛkkarma*), and (2) the visibility-correction due to the Sun's northward or southward course (i.e., ecliptic-deviation) (*ayana-dṛkkarma*).

Let Fig. 21 represent the celestial sphere for the local place. SEN is the eastern horizon and Z the zenith ; ♈E is the equator and P its north pole ; ♈T is the ecliptic and K its north pole. Suppose that the Moon is rising at the point M′ on the horizon. Let M be the point where the secondary to the ecliptic (*kadambaprota-vṛtta*) drawn through M′ intersects the ecliptic, L the point where the hour circle (*dhruvaprota-vṛtta*)

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[1] The same rule is found to occur in *BrSpSi,* vi. 4 ; *ŚiDVṛ, I,* vii. 3 (ii) ; *MSi,* vii. 4 ; *SiŚe,* ix. 7.

drawn through M′ intersects the ecliptic[1], and T the point where the horizon intersects the ecliptic.[2] Then the arc MT of the ecliptic denotes the total visibility-correction ; the arc ML denotes the visibility — correction due to ecliptic-deviation (*ayana-dṛkkarma*); and the arc LT denotes the visibility correction due to the latitude of the local place (*akṣa-dṛkkarma*). The visibility-correction for a planet is defined in the same manner.

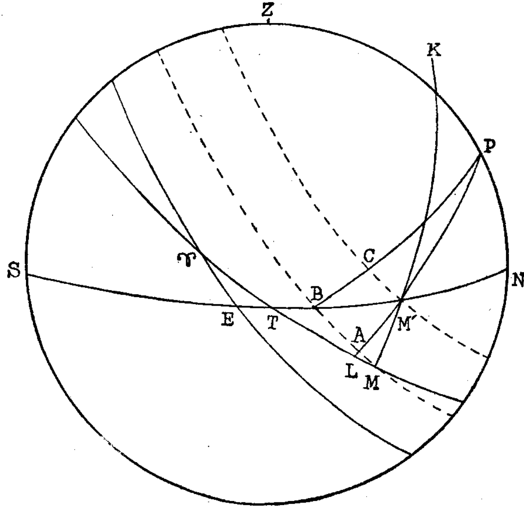



Fig. 21

The correction stated in the above stanzas is the *akṣa-dṛkkarma* for the Moon. The formula stated is

$$akṣa\text{-}dṛkkarma = \frac{\text{Rsin}\ \phi \times \text{Moon's latitude}}{\text{Rcos}\ \phi},$$

where $\phi$ is the latitude of the local place.

This formula is approximate. Let A be the point where the diurnal circle through M intersects the hour circle through M′, B the point where the diurnal circle through M intersects the horizon, and C the point where the hour circle through B intersects the diurnal circle through M′. Then proceeding as for finding the earthsine, it can be easily shown that

$$\text{arc CM}' = \frac{\text{Rsin}\ \phi \times \text{Rsin (arc BC)}}{\text{Rcos}\ \phi} \quad \text{approx.}$$

$$= \frac{\text{Rsin}\ \phi \times \text{Moon's latitude}}{\text{Rcos}\ \phi} \quad \text{approx.}$$

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[1] The point L is called *ayana-graha* or *āyana-graha*. See *ŚiDVṛ, I.* vii. 2,4.

[2] T is called *dṛg-graha*. See *ŚiDVṛ, I,* vii. 4.

It follows that the formula given in the text actually gives an approximate value of the arc CM′ or AB.[1]

The rule stated in the text has been generally used in the cases where the latitude of the body concerned is small. In the cases of fixed stars whose latitudes may be considerable, a more accurate rule is prescribed.[2]

When the Moon's latitude is north, the longitude of the point T is smaller or greater than the longitude of the point L according as the Moon M′ is rising or setting; and when the Moon's latitude is south, the longitude of the point T is respectively greater or smaller; hence the rule of addition and subtraction stated in the text.

A rule relating to the visibility correction known as *ayana-dṛkkarma*:

2(ii)-3. Divide the product of the Rversed-sine of the Moon's longitude diminished by three signs, the Rsine of the Sun's greatest declination, and the Moon's latitude by the square of the radius. Whatever is thus obtained, say the learned, should be subtracted from the Moon's longitude provided that her *ayana* and latitude are of like direction; in the contrary case, that result should always be added to the Moon's longitude.[3]

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[1] That this formula gives an approximate value of arc AB may be demonstrated as follows:

Since MM′ is small, we may treat the triangle M′BA as plane. Then from the triangle M′BA, we have

$$\begin{aligned} AB &= \frac{\text{Rsin}\,\angle\,BM'A \times M'A}{\text{Rsin}\,\angle\,M'BA} \\ &= \frac{\text{Rsin}\,\angle\,BM'A \times M'M}{\text{Rsin}\,\angle M'BA} \quad \text{approx.} \\ &= \frac{\text{Rsin}\,\phi \times \text{Moon's latitude}}{\text{Rsin}\,\phi} \quad \text{approx.} \end{aligned}$$

See E. Burgess, *SūSi*, vii. 7-12, notes,

[2] See *BrSpSi*, x. 18-19; *ŚiDVṛ*, *I*, xi. 12-13; and *SiŚi*, *I*, vii. 6. Bhāskara II has given a slightly modified formula for small latitudes also. See *SiŚi*, *I*. vii. 7. The most accurate formula for the *akṣa-dṛkkarma* occurs in *SiTV*, vii. 103-104.

[3] This rule occurs also in *ŚiDVṛ*, *I*, vii. 2-3(i) and *SiŚe*, ix. 4, 5. The same rule in a modified form occurs in *BrSpSi*, vi. 3; x. 17 and in *MSi*, vii. 2, 3. More accurate rules occur in *SiŚi*, *I*, vii. 4, 5 and in *SiTV*, vii. 77-80.

That is

$$ayana\text{-}d\d{r}kkarma = \frac{\text{Rversin } (M - 90°) \times \text{Rsin } \epsilon \times \text{Moon's latitude}}{\text{R} \times \text{R}},$$

where $M$ denotes the Moon's (*sāyana*) longitude and $\epsilon$ the Sun's greatest declination.

This formula is also approximate. Referring to the previous figure, we have

$$\text{arc MA} = \frac{\text{Rsin } \angle\text{MM'A} \times \text{Rsin (arc MM')}}{\text{R}} \text{ approx.}$$

$$= \frac{\text{Rsin } \angle\text{KMP} \times \text{Rsin (arc MM')}}{\text{R}} \text{ approx.}$$

$$= \frac{ayana\text{-}valana \times \text{Moon's latitude}}{\text{R}} \text{ approx.}$$

$$= \frac{\text{Rversin } (M - 90°) \times \text{Rsin } \epsilon \times \text{Moon's latitude}}{\text{R} \times \text{R}},$$

on substituting the value of the *ayana-valana*.[1]

The formula stated in the text, therefore, is an approximate value of the arc MA, or ML, which is the *ayana-dṛkkarma*.

When the *ayana*[2] and latitude of the Moon are of like directions, the longitude of the point L is smaller than the longitude of the point M; and when the *ayana* and latitude of the Moon are of unlike directions, the longitude of the point L is greater than the longitude of the point M; hence the rule of addition and subtraction stated in the text.

The visibility-corrections should be applied as follows. The true longitude of the Moon (which corresponds to the longitude of the point M of the ecliptic) should be first corrected for the *ayana-dṛkkarma*: the resulting longitude corresponds to that of the point L of the ecliptic. This is technically called the polar longitude of the Moon. This polar longitude should then be corrected for the *akṣa-dṛkkarma*: the longitude thus obtained corresponds to that of the point T of the ecliptic, which rises (or sets) with the Moon's disc. This is technically called the longitude of the visible Moon (*dṛśya-candra*).

In the text the order of the corrections is reversed. The difference is negligible.

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[1] *Vide supra*, chapter V, stanza 45, p. 171,

[2] *Vide supra*, p. 171 (footnote).

A rule relating to the visibility of the Moon:

4-5(i). The Moon's longitude, which is obtained in this way after the application of the above-mentioned (visibility) corrections, is stated by the learned to be the longitude of the visible Moon (i.e., the longitude of that point of the ecliptic which rises with the Moon).

When the *prāṇas*[1] (of the oblique ascension) due to the degrees intervening between the Sun and the (visible) Moon,[2] reduced to *ghaṭīs*, amount to two, then the Moon is seen to rise in the clear, cloudless, starry sky after sunset.[3]

The latter part of the above passage relates to the visibility of the Moon, or, in other words, the heliacal rising of the Moon. On the fifteenth lunar day of the dark half of the month, the Moon comes near the Sun from behind and is lost in his splendour. After about two days it is beyond the limit of invisibility and is again seen in the sky after sunset, being in advance of the Sun.

In order to see whether the Moon will be visible on the first or second lunar day of the light half of the month, one should calculate the (*sāyana*) longitude of the Sun for sunset on that day and also the (*sāyana*) longitude of the Moon corrected for the visibility corrections for the same time. If the oblique ascension of the part of the ecliptic lying between the Sun and the Moon thus obtained is equal to or greater than two *ghaṭīs*, the Moon will be visible after sunset that day, otherwise not. Similarly, in order to test whether the Moon will be visible in the night just (before she sets heliacally) on the fourteenth or fifteenth lunar day of the dark half of the lunar month, one should calculate the (*sāyana*) longitude of the Sun for sunrise following that night and also the (*sāyana*) longitude of the Moon corrected for the visibility corrections for the same time. If the oblique ascension of the part of the ecliptic lying between the Sun and the Moon thus obtained is equal to or greater than two *ghaṭīs*, the Moon will be seen before sunrise, otherwise not.

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[1] *Prāṇa* is the same as *asu*.

[2] Both *sāyana*.

[3] This rule is found to occur also in *PSi*, v. 3; *BrSpSi*, vi. 6; x. 32; *ŚiDVṛ*, *I*, vii. 5; *SiŚe*, ix. 8(i), 13.

A rule for calculating the phase of the Moon:

5(ii)-7. (In the light half of the month) multiply (the diameter of) the Moon's disc by the Rversed-sine of the difference between the longitudes of the Moon and the Sun (when less than a quadrant) and divide (the product) by the number 6876: the result is always taken by the astronomers to be the measure of the illuminated part (of the Moon). When the difference between the Moon and the Sun exceeds a quadrant, then the Moon's illuminated part is calculated from the Rsine of that excess increased by the radius.[1]

After full Moon (i.e., in the dark half of the month) the unilluminated part of the Moon is determined from the Rversed-sine or Rsine of (the excess over six or nine signs respectively of) the difference between the longitudes of the Moon and the Sun in the same way as the illuminated part is determined (in the light half of the month).

Let the longitude of the Moon minus the longitude of the Sun be denoted by $D$. Then according to the above rule—

(1) *In the light half of the month*, the illuminated part of the Moon

$$= \frac{\text{Rversin } D \times \text{Moon's diameter}}{6876},$$

if $D < 3$ signs, i.e., if it is the first quarter of the month; and

$$= \frac{[\text{R} + \text{Rsin } (D - 90°)] \times \text{Moon's diameter}}{6876},$$

if $D > 3$ signs, i.e., if it is the second quarter of the month.

(2) *In the dark half of the month*, the unilluminated part of the Moon

$$= \frac{\text{Rversin } (D - 180°) \times \text{Moon's diameter}}{6876},$$

if $D > 6$ signs, i.e., if it is the third quarter of the month; and

$$= \frac{[\text{R} + \text{Rsin } (D - 270°)] \times \text{Moon's diameter}}{6876},$$

if $D > 9$ signs, i.e., if it is the last quarter of the month.

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[1] This rule is found to occur also in *BrSpSi*, vii. 11(ii)-12 and *ŚiDVṛ*, *I*, ix. 12.

Consider Fig. 22. The sphere centred at M is the Moon's globe, and E is the centre of the Earth. The lines MS′ and ES (which are approximately parallel to each other) are directed towards the Sun. Half the globe of the Moon bounded by the circle ABCD and lying towards the Sun is illuminated by the rays of the Sun, and half the globe bounded by the circle LBTD and lying towards E is visible from the Earth. An observer on the Earth will, therefore, see only that part of the Moon's illuminated surface which lies between the semicircles BCD and BTD. In fact, he will see the projection of that on the plane of the circle LBTD. Let BZD be the projection of the semicircle BCD on the plane LBTD. Then the observer will see that part of the Moon's disc illuminated by the Sun which lies between BTD and BZD. This illuminated part of the Moon's disc is measured by the length ZT of the Moon's diameter.

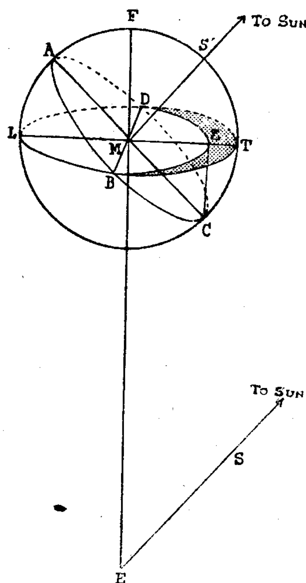


Fig. 22

From the figure, it is evident that

$$\angle \text{CMZ} = \angle \text{FMS}' = \angle \text{MES},$$

so that from the plane triangle CZM right-angled at Z, we have

$$\text{MZ} = \frac{\text{Rcos} \angle \text{CMZ} \times \text{MC}}{\text{R}}.$$

$$\text{Therefore ZT} = \text{MT} - \text{MZ}$$

$$= \frac{(\text{R} - \text{Rcos} \angle \text{CMZ}) \times \text{MC}}{\text{R}}$$

$$= \frac{\text{Rversin} \angle \text{CMZ} \times \text{MC}}{\text{R}}$$

$$= \frac{\text{Rversin} \angle \text{MES} \times \text{MC}}{\text{R}}.$$

Hence the rule.

A rule for the determination of the Moon's true declination, i.e., the declination of the centre of the Moon's disc :

8. Take the sum of the arcs of the Moon's declination and (celestial) latitude when they are of like directions ; in the

contrary case, take their difference. Then take the Rsine of that (sum or difference). (This is the Rsine of the Moon's true declination).[1] From that calculate the *nāḍīs* of the ascensional difference of the Moon.

The Moon's true declination is used in finding the radius of the Moon's diurnal circle and the Moon's ascensional difference. The process is the same as that for the Sun.

A rule for the determination of the base (*bāhu*) and upright (*koṭi*) to be used in the graphical representation of the elevation of the Moon's horns, when the calculation is made in the first quarter of the month for sunset:

9-12. (Calculate the longitudes of the Sun and the visible Moon for sunset on the day of calculation). By the help of the *asus* intervening between the Sun and the (visible) Moon always find out, in the manner stated before, the Rsine of the Moon's altitude. Then divide the product of the Rsine of Moon's true altitude (thus obtained) and the Rsine of the (local) latitude by the Rsine of the colatitude: thus is obtained the Moon *śaṅkvagra*, which is always to the south of the Moon's rising-setting line. Then multiply (the Rsine of) the Moon's true declination by the radius and divide (the resulting product) by the Rsine of the colatitude: thus is obtained the so called Rsine of the *agrā* of the (apparent) Moon lying to the north or south (of the ecliptic). Take their sum (i.e., the sum of the Rsines of the Moon's *śaṅkvagra* and *agrā*) when they are of like directions, and the difference when they are of unlike directions. Then reversely add or subtract the Rsine of the Sun's *agrā*. Then is obtained the true value of the Moon's base (*bāhu*). Then Rsine of the Moon's altitude is the upright (*koṭi*).

The *asus* intervening between the Sun and the visible Moon are the *asus* of the oblique ascension of that part of the ecliptic which lies between

[1] This rule occurs also in *BrSpSi*, vii. 5; *ŚiDVṛ, I*, viii. 2; *SiŚe*, x. 7. It is obviously approximate. A better and more accurate rule occurs in *SiŚi, I*, vii. 3 and 13.

the Sun and the visible Moon. These correspond to the time to elapse before moonset.

The Moon's *agrā* and *śaṅkvagra* are defined in the same way as in the case of the Sun.[1]

The base (*bāhu* or *bhuja*) for a planet is the distance of the foot of the perpendicular dropped from the planet on the plane of the horizon from the east-west line. It is equal to

$$\text{śaṅkvagra} \pm \text{Rsin (agrā)},$$

+ or - sign being taken acccording as the *śaṅkvagra* and the Rsine of the *agrā* are of like or unlike directions.

The true value of the Moon's base (usually called *spaṣṭa-bāhu* or *spaṣṭa-bhuja*) denotes the north-south distance between the projections of the Sun and the Moon on the plane of the horizon. It is equal to

$$\text{Moon's base} \pm \text{Sun's base},$$

+ or — sign being taken according as the bases of the Sun and the Moon are of unlike or like directions. When the Sun is on the horizon as in the case contemplated in the above stanzas, is is equal to

$$\text{Moon's base} \pm \text{Sun's agrā.}^{2}$$

The upright denotes the difference between the Rsines of the altitudes of the Moon and the Sun. In the present case, the Sun's altitude is zero, so that the upright is equal to the Rsine of the Moon altitude.

The base and the upright defined above will be required in the stanzas below.

## Method for the graphical representation of the elevation of the lunar horns in the first quarter of the month at sunset:

13-17. To the north or south of the Sun is (to be laid off) the (true) base (according to its direction); and to the east[3] (of the point thus obtained) is (to be laid off) the upright; the line which joins the ends of the base and the upright is called the hypotenuse. (Taking the centre) at the meeting point of the hypotenuse and the upright, draw the Moon's disc. The

[1] *Vide supra,* chapter III, stanzas 37 and 54, pp. 84 and 93.

[2] The Sun's base in this case is the same as the Sun's *agrā*.

[3] The upright is laid off towards the east because in the light half of the month the Moon is towards the east of the Sun.

hypotenuse is the east-west line of that (Moon's disc); through the middle of that (i.e., through the centre of the Moon's disc) draw the north-south line. At the extremities of the north-south line mark two points on the periphery of the Moon's disc. (Then lay off the Moon's illuminated part) along the hypotenuse (from the west point) towards the interior of the Moon's disc and mark there the point of illumination. Thereafter always draw a circle passing through the (above-mentioned) three points. The portion lying between that (circle) and the (periphery of the) Moon's disc (lying towards the Sun) is called the illuminated part (of the Moon). The elevation, depression, or horizontalness of the Moon's horns, in whatever unit be it measured (in the figure), is clearly perceived in the sky (as in the figure).[1]

In Fig. 23, AB is the base and MA the upright. Then, according to Bhāskara I, B denotes the Sun's centre and M the Moon's centre. The circle NESW centred at M is the Moon's disc, the points N, E, S, and W being the north, east, south, and west points on its periphery. The measure of the illuminated part of the Moon, IW, is laid off from W towards M and an arc of a circle is drawn through N, I, and S.[2] The shaded portion lying between this arc and the arc NWS is the illuminated part of the Moon's disc. The cusps at N and S are called the Moon's horns. The figure shows that in the present case the case the northern horn is higher than the southern one.

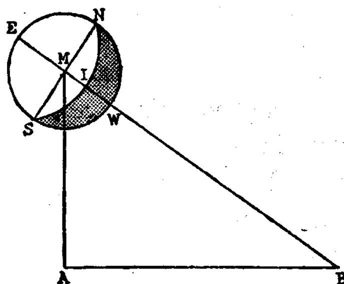



Fig. 23

Representation of the elevation of the lunar horns at any other time instead of sunset in the first quarter of the month :

18. This (above) method is to be followed at sunset. At (any other) given time, all calculations such as the determination

[1] This rule is approximate. For other rules, see *BrSpSi*, vii. 7-10; *ŚiDVṛ*, *I*, ix; *SiŚi. I*, ix.

[2] The point I is called "the point of illumination" (*sitabindu*).

of the Rsine of the zenith distance of the Moon for that time are prescribed to be made with the setting point of the ecliptic (taken for the Sun).

The only difference in this case is that the time to elapse before moonset, instead of being found out from the *asus* intervening between the Moon and the Sun (as was done in the previous case), should be found out in this case from the *asus* intervening between the Moon and the setting point of the ecliptic, or, as the commentator Parameśvara says, from the *asus* intervening between the rising point of the ecliptic and the point six signs in advance of the Moon. The *asus* correspond to oblique ascension as in the previous case.

Representation of the elevation of the lunar horns in the second quarter of the month:

19. (When the calculation relating to the elevation of the Moon's horns is made) after the eighth lunar day, the rising point of the ecliptic itself should be regarded as the Sun. And under that assumption should be made the calculation of the Rsine of the Moon's altitude, etc., with the exception of the calculation of the measure of the illuminated part (of the Moon's disc).

A rule for the determination of the Rsine of the Moon's altitude to be used in connection with the elevation of the lunar horns:

20. The Rsine of the Moon's altitude should be calculated from the *asus* intervening between the Sun and the Moon, or between the rising or setting point of the ecliptic and the Moon subject to the time of calculation, the *asus* being those obtained by applying the rule once and not successively.

A rule telling that the above calculations pertaining to the elevation of the lunar horns relate to the first half of the month only:

21. In this manner, at sunset or any other time, with the help of the longitudes of the Sun, Moon and the Moon's ascending node, should be made this calculation relating to the Moon till the fifteenth lunar day: so has been said.

A rule telling how many *nāḍīs* before or after sunset will the Moon be seen to rise on the full Moon day:

22. Diminish the *nāḍīs* (due to the oblique ascension of the part of the ecliptic) intervening between the Sun and the (visible) Moon (at sunset on the full moon day) (from or) by (the *nāḍīs* of) the length of the day: so many *nāḍīs* before or after sunset is the Moon seen (to rise on the full moon day).[1]

A rule relating to the representation of the elevation of the lunar horns in the dark half of the month:

23-25. After the end of the (light) fortnight, the Moon, lying above the horizon, is drawn by using the measure (of the Rsine of the Moon's altitude) computed from (the *asus* due to the oblique ascension of the part of the ecliptic intervening between the visible Moon and) the rising point of the ecliptic at the given time. The upright is laid off towards the west[2]; the base is laid off along the north-south line (in its proper direction); and the hypotenuse-line is stretched out from the end of that (base) to meet the end of the upright. Then from the east point (of the Moon's figure) lay off the measure of the (Moon's) illuminated part along the hypotenuse-line within the figure of the Moon; or, from the west point (of the Moon's figure), lay off the (measure of the Moon's) unilluminated part.

A rule telling how to do the same at sunrise in the dark half of the month:

26. Or, perform the operation, stated above, concerning the Moon's illuminated or unilluminated part at sunrise with the *asus* intervening between the (visible) Moon and the Sun at that time. The time of moonrise will now be told.

[1] This rule gives an approximate time of moonrise. In order to obtain the nearest approximation to the correct time of moonrise use should be made of the method of successive approximations. See *infra* stanzas 31-35.

[2] Because in the dark fortnight the Moon is to the west of the Sun.

A rule for getting the duration of the Moon's visibility at night in the light half of the month (I quarter):

27. In the light fortnight, find out the *asus* due to oblique ascension (of the part of the ecliptic) intervening between the Sun and the (visible) Moon (at moonset) both increased by six signs, by the method of successive approximations. These give the duration of visibility of the Moon (at night) (or, in other words, the time of moonset).[1]

The process of successive approximations may be explained as follows: Compute the (*sāyana*) longitudes of the visible Moon and the Sun for sunset and increase both of them by six signs. Then find out the *asus* ($A_1$) due to the oblique ascension of the part of the ecliptic lying between the two positions thus obtained. Then $A_1$ *asus* denote the first approximation to the duration of the Moon's visibility at night. Then calculate the displacements of the Moon and the Sun for $A_1$ *asus* and add them respectively to the longitudes of the visible Moon and the Sun for sunset and increase the resulting longitudes by six signs; and then find out the *asus* ($A_2$) due to the oblique ascension of the part of the ecliptic lying between the two positions thus obtained. Then $A_2$ *asus* denote the second approximation to the duration of the Moon's visibility at night. Repeat the above process successively until the successive approximations to the duration of the Moon's visibility agree to *vighaṭīs*.

The time thus obtained is in terms of civil reckoning. If, however, the use of the Moon's displacement alone be made at every stage, the time obtained will be in terms of sidereal reckoning.

A rule for finding the time of moonrise in the dark half of the month (III quarter):

28. Thereafter (i.e., in the dark half of the month), the Moon is seen (to rise) at night (at the time) determined by the *asus* (due to oblique ascension) derived by the method of successive approximations from the part of the ecliptic intervening between the Sun as increased by six signs and the (visible) Moon as obtained by computation, (the Sun and the Moon both being those calculated for sunset).[2]

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[1] *Cf.* *SūSi*, x. 2-4. [2] *Cf.* *SūSi*, x. 5.

In the night, the time is measured since sunset.

Details of the method of successive approximations contemplated in the above rule:

29-31. Determine the time in *asus* (due to the oblique ascension of the part of the ecliptic) intervening between the rising point of the ecliptic and the (visible) Moon computed for sunset. (This is the first approximation to the required time). Now calculate the positions of the rising point of the ecliptic and the (visible) Moon for that time; and then determine the *asus* intervening between those positions again. In case the longitude of the (visible) Moon is greater than that of the rising point of the ecliptic, add these *asus* to the time obtained above; in the contrary case, subtract them. (This is the second approximation to the required time). Repeat this process successively until the successive approximations to the time, the longitude of the rising point of the ecliptic, and the longitude of the (visible) Moon are (severally) equal (up to *vighaṭīs* or minutes). At the time ascertained by this procedure for the Moon, the Moon is seen (to rise) in the night filling (the space in) all the directions with her rays.

The above rule is based on the fact that at moonrise the longitudes of the visible Moon and the rising point of the ecliptic are the same.

An alternative rule for finding the time of moonrise in the dark half of the month (III quarter):

32-33. Find out the *asus* due to the oblique ascension of the part of the ecliptic lying from the setting Sun up to the (visible) Moon; and therefrom subtract the length of the day. (This approximately gives the time of moonrise as measured since sunset). Since the Moon is seen (to rise) at night when so much time, corrected by method of successive approximations, is elapsed, therefore the *asus* obtained above should be operated upon by the method of successive approximations.

Details of the method of successive approximations contemplated in the above rule :

34. Find out the displacements of the Sun and the Moon for the *ghaṭīs* (corresponding to the approximate time) obtained above and add them to the longitudes of the Sun and the (visible) Moon respectively ; then determine the *ghaṭīs* (due to the oblique ascension of the part of the ecliptic) intervening between them ; and then from those (*ghaṭīs*) subtract the length of the day. (Thus is obtained the second approximation to the required time). Then find out the the displacements of the Sun and the Moon corresponding to (the *ghaṭīs* of) the remainder (and proceed as above again and again until the successive approximations agree to *vighaṭīs*).

An analogous rule for finding the time of moonrise in the light half of the month (II quarter) :

35-36. (In the light half of the month) when the measure of the day exceeds the *nāḍīs* (due to the oblique ascension of the part of the ecliptic) lying between the Sun and the (visible) Moon (computed for sunset), the moonrise is said to occur in the day when the residue of the day (i.e., time to elapse before sunset) is equal to the *ghaṭīs* of their difference. (In this case) the longitudes of the Sun and the (visible) Moon should be diminished by their displacements determined by proportion from the *nāḍīs* (of the residue) ; and then should be obtained the *asus* (due to the oblique ascension of the part of the ecliptic) between the Sun and the (visible) Moon (thus obtained). These *asus* should then be operated upon by the method of successive approximations.

Another rule for getting the time of moonrise in the dark half of the month (IV quarter) :

37-38. Determine the *asus* (due to the oblique ascension of the part of the ecliptic lying) from the (visible) Moon at sunrise up to the rising Sun ; then subtract the corresponding displacements (of the Moon and the Sun) from them (i.e., from

the longitudes of the visible Moon and the Sun computed for sunrise) ; and on them apply the method of successive approximations (to obtain the nearest approximation to the time between the visible Moon and the Sun computed for moonrise, i.e., between the risings of the Moon and the Sun). The Moon, who is like a looking glass for the face of the directions, rises as many *asus* before sunrise as correspond to the *nāḍīs* obtained by the method of successive approximations.

A rule for the determination of the time of the meridian passage of the Moon, and the longitudes of the Moon and the meridian-ecliptic point at that time :

39. Infer by your intellect the time when the meridian-ecliptic point and the Moon are together. Then, by the method of successive approximations, find out the nearest approximations for that time, the longitude of the Moon, and the longitude of the meridian-ecliptic point (for that time).

Assuming that the rising point of the ecliptic is three signs in advance of the meridian-ecliptic point, the time to elapse before or elapsed since the Moon is on the meridian is the same as the time to elapse before or elapsed since the point of the ecliptic three signs in advance of the Moon is on the horizon. Therefore in order to get an approximate time when the Moon occupies the meridian-ecliptic point one may proceed as follows : First calculate the longitudes of the Sun, the Moon, and the rising point of the ecliptic with the help of the given time. Then increase the longitude of the Moon by three signs and find the time due to the oblique ascension of the part of the ecliptic lying between the rising point and the Moon as increased by three signs. The time thus obtained is the approximate time to elapse before or elapsed since the meridian passage of the Moon. From this calculate the time of the meridian passage of the Moon.

Details of the method of successive approximations contemplated in the above rule :

40. Determine the *nāḍīs* intervening between the Moon and the meridian-ecliptic point (for the time determined by inference) with the help of the times of rising of the signs at Laṅkā. When (the longitude of the Moon is) less (than the

longitude of the meridian-ecliptic point), subtract the resulting *nāḍīs* from those corresponding to the inferred time; when greater, addition is prescribed. (For the time thus obtained calculate the longitudes of the Moon and the meridan-ecliptic point and find the *nāḍīs* intervening between them with the help of the right ascensions of the signs as before; and then repeat the above process successively until the nearest approximation to the time of meridian passage of the Moon is obtained).

A rule for the determination of the Rsine of the Moon's meridian zenith distance:

41. By this process is obtained the Moon when she is on the meridian (lit. when her longitude is equal to that of the meridian-ecliptic point). From her celestial latitude and declination, and from the (local) latitude is determined the Rsine of her meridian zenith distance.

First obtain the Moon's true declination by rule 8 above; then apply the following formula:

Moon's meridian zenith distance = local latitude $\pm$ true declination, + or − sign being taken according as the Moon is to the south or to the north of the equator.

A rule regarding the elevation of the horns of the half-risen or half-set Moon:

42. The determination of the elevation of the horns of the half-risen or half-set Moon is made with the help of the *agrā* of the rising or setting point of the Moon's orbit.

When the Moon is rising or setting, its base is obviously equal to the *agrā* of the rising or setting point of the Moon's orbit.

The text does not say anything about the base and depth of the Sun lying below the horizon but these elements have to be calculated and made use of in the above-mentioned determination.

Procedure to be adopted in the case of the planets:

43. This (above-mentioned) procedure should be adopted in the case of the nector-rayed Moon; the same process is prescribed for all the planets also.

**The remainder of this chapter deals exclusively with the planets.**

Minimum distances of the planets from the Sun when they are visible :

44. Venus is visible when it is 9 degrees away from the Sun ; Jupiter, Mercury, Saturn, and Mars are observed when they are respectively further away by two degrees in succession (i.e., when they are respectively 11°, 13°, 15°, and 17° away from the Sun).

45. Ve_ us, which moves in its proper orbit but appears retrograde, is visible, due to profusion of its rays[2], when it is (only) $4\frac{1}{2}$ or 4 degrees away from the Sun.

The degrees above are "the degrees of time" (called *kālabhāga*). One degree of time is equivalent to 60 *asus*. Thus Venus is visible in the east if the time taken by the part of the ecliptic between the Sun and Venus to rise above the eastern horizon amounts at least to $9 \times 60$ *asus* ; and in the west, if the time taken by the part of the ecliptic between the Sun and Venus to set below the western horizon, or the time taken by the diametrically opposite part of the ecliptic to rise above the eastern horizon, amounts at least to $9 \times 60$ *asus*[3]. It may be pointed out that a sign sets in the same time that the seventh, i.e., the diametrically opposite sign, takes to rise.

According to Lalla, Mercury and Venus, when in regression, are visible when they are respectively 12 and 8 degrees distant from the Sun.[4] According to Śrīpati, Mercury and Venus, when near their apogees, are visible when they are respectively 14 and 10 degrees distant from the Sun ; and when in regression, they are visible when respectively 12 and 8 degrees distant from the Sun.[5]

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[1] The same degrees of visibility are prescribed also in *BrSpSi*, vi. 6 ; x. 32 ; *ŚiDVṛ*, *I*, vii. 5 (i) ; and *SiŚe*, ix. 8 (i), 12.

[2] When Mercury or Venus is in retrograde motion, it is nearer to the Earth and so its size is a little enlarged.

[3] Venus in both the cases being that corrected for the visibility corrections.

[4] *ŚiDVṛ*, *I*, vii. 5 (ii).

[5] *SiŚe*, ix. 9. The Greek astronomer Ptolemy (150 A. D.) also considered the heliacal rising and setting of the planets and defined the limits of visibility of each planet when in the sign Cancer (i.e., when the equator and the ecliptic are nearly parallel). His limits are ; for Saturn, 14° ; for Jupiter, 12°45′ ; for Mars, 14°30′ ; and for Venus and Mercury, in the west, 5°40′ and 11°30′ respectively. *Vide Syntaxis*, xiii. 7-9.

A rule telling us (1) how to convert the degrees of time into *vighaṭīs*, and (2) how to determine the degrees of time between the Sun and a planet :

46-47. These degrees of time when multiplied by ten are called *vighaṭīs*. (When the planet is seen) in the east, they are determined from (the oblique ascension of) the sign occupied by the Sun and the planet ; (when the planet is visible) in the west, they are determined from (the oblique ascension of) the seventh sign (as measured from the sign occupied by the Sun and the planet).[1] (The process is as follows) : Divide the oblique ascension of the sign occupied by the Sun and the planet (or of the seventh sign, as the case may be) as multiplied by the degrees of the difference between the longitudes of the planet and the Sun by 30. If the resulting time is equal to (or greater than) that stated (for that planet), the planet will be seen to rise (heliacally).

The longitude of the planet is that corrected for the visibility-corrections.

## CONJUNCTION OF PLANETS

Definition of the "divisor" to be used later :

48. The *śīghra-karṇa* as multiplied by the *mandocca-karṇa* (or *manda-karṇa*) should be divided by the radius : the result thus obtained is called the "divisor".[2]

This "divisor" denotes the distance between the Earth and a planet (*bhū-tārāgraha-vivara*). The above rule for the divisor was probably derived by proportion as follows : "If the radius of the *śīghra* concentric denotes the *manda-karṇa*, what will the *śīghra-karṇa* stand for ? The result is the geocentric distance of the planet, the so called "divisor".

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[1] *Cf.* *ŚiDVṛ*, *I*, vii. 5 (iv).

[2] *Cf.* *ŚiDVṛ*, *I*, x. 1.

A rule relating to the determination of the time and the common longitude of two planets when they are in conjunction in longitude :

49-51. If one planet is retrograde and the other direct, divide the difference of their longitudes by the sum of their daily motions ; otherwise (i.e., if both of them are either retrograde or direct), divide that by the difference of their daily motions : thus is obtained the time in terms of days, etc., after or before which the two planets are in conjunction (in longitude). The velocity of the planets being different (literally, manifold) (from time to time), the time thus obtained is gross (i.e., approximate). One, proficient in astronomical science, should, therefore, apply some method to make the longitudes of the two planets agree to minutes. Such a method is possible from the teachings of the precepter or by day to day practice (of the astronomical science).[1]

The method to be used here is obviously the method of successive approximations.

A rule relating to the computation of the celestial latitude of a planet when it is in conjunction with another planet:

52-53. Diminish the longitude of the planet in conjunction with another planet by the degrees of (the longitude of) the ascending node (of that planet) ; by the Rsine of that multiply the greatest latitude (of the planet) and divide (the product) always by the (corresponding) "divisor" (defined in stanza 48) : thus is obtained the latitude of Jupiter, Mars, or Saturn. In order to find the latitudes, north or south, of the remaining planets (Mercury and Venus), subtraction (of the degrees of the longitude of the ascending node) should be made from the longitude of the planet's *śīghrocca*.[2]

The longitude of the planet to be used in the above rule is really the heliocentric longitude and not the geocentric longitude. Brahmagupta

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[1] *Cf. BrSpSi*, ix. 5-6 ; *ŚiDVṛ, I*, x. 7-9 (i) ; *SiŚe*, xi. 12-13.

[2] This rule occurs also in *ŚiDVṛ, I*, x. 10, 9 (ii)

(628 A. D.) has therefore prescribed the use of the true-mean longitude of the planet in the case of Mars, Jupiter and Saturn, and that of the longitude of the planet's *śighrocca* as corrected for the planet's *mandaphala* in the case of Mercury and Venus.[1]

A rule relating to the distance between two planets which are in conjunction in longitude:

54-55. When the latitudes of the two planets (in conjunction) are of unlike directions, their sum is the (angular) distance between them. When their latitudes are of like directions, the minutes of the distance between them are obtained by taking their difference.[2]

The (linear) distance between the two planets (in conjunction) should be announced by those proficient in the processes of planetary conjunction by taking a minute as equivalent to one-fourth or one-half of an *aṅgula*, whichever agrees with the phenomenon observed in the sky.

According to the commentator Parameśvara, one minute of the distance between the two planets is equal to one-half or one-fourth of an *aṅgula*, according as the two planets are or are not near the horizon.

Brahmagupta has criticised the longitudinal conjunction of the planets.[3] He favours horizontal conjunction which occurs when the two planets are on the same secondary to the prime vertical, because it can be easily observed.

Diameters of the planets in minutes of arc:

56. Having (first) divided 32 by 5, divide the same number (i.e., 32) again and again by the same (5) as increased by itself in succession (i.e., by 10, 15, 20, and 25): the results thus obtained are known as the minutes of the diameters of Venus, Jupiter, Mercury, Saturn, and Mars respectively.

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[1] See *BrSpSi*, ix. 9. Also see *SūSi*, ii. 56-57; *SiŚe*, xi. 15; and *SiŚi*, *II*, vi. 20-25(i).

[2] This rule occurs also in *ŚiDVṛ*, *I*. x. 11; *KPr*, vii. 8; and has been quoted by Brahmagupta in *BrSpSi*, ix 11, and by Śrīpati in *SiŚe*, xi. 18.

[3] In *BrSpSi*, ix. 11-12. Also see *SiŚe*, ix. 19-20.

According to Āryabhaṭa I,[1] the diameter of the Moon is 315 *yojanas*, and the diameters of Venus, Jupiter, Mercury, Saturn, and Mars are respectively one-fifth, one-tenth, one-fifteenth, one-twentieth, and one-twenty-fifth of the diameter of the Moon (at the Moon's mean distance). It follows that

the diameter of a planet in minutes

$$= \frac{\text{diameter of the planet in } yojanas \times R}{\text{Moon's mean distance in } yojanas}$$

$$= \frac{\text{diameter of the planet in } yojanas}{10} \text{ approx.}$$

$$= \frac{\text{diameter of the Moon in } yojanas}{10 \times D} \text{ approx.,}$$

where $D = 5, 10, 15, 20$, or $25$, according as the planet is Venus, Jupiter, Mercury, Saturn, or Mars.

$$= \frac{32}{D} \text{ approx.}$$

Hence the rule in the text.

Definition of the "dividing numbers" for the planets :

57. (Severally) multiply the *yojanas* of the Moon's (mean) distance by the same numbers (i.e., by 5, 10, 15, 20 and 25) : the result, in each case, is the "dividing number", in terms of *yojanas*, used in the determination of the *lambana* and *nati* (for the respective planets).

The "dividing numbers" denote the mean distances of the planets under the assumption that the diameter of each of them is 315 *yojanas* (the same as that of the Moon).

A rule for finding the true distance of a planet, assuming 315 *yojanas* for its diameter, in terms of *yojanas* :

58 (i). These (above-mentioned) "dividing numbers" become accurate when multiplied by the "divisor" and divided by the radius.

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[1] *A*, i. 7.

The obvious proportion is: When the radius (i.e., 3438′) corresponds to the planet's mean distance in *yojanas*, what will the divisor (i.e., the true distance of the planet in minutes) correspond to ? The result is the true distance of the planet in terms of *yojanas*.

A rule relating to the determination of the true values of the diameters of the planets in minutes :

58 (ii). So also become the minutes of the diameters when divided by the "divisor" and multiplied by the radius.[1]

The remaining processes concerning the occultation of one planet by another :

59-60. The determination of the ten Rsines (viz. *madhyajyā*, *dṛkkṣepajyā*, *dṛggatijyā*, *dṛgjyā* and *udayajyā*—five for each of the two planets concerned) and other remaining determinations should be made as in the case of the Moon. The Rsine of the altitude (for each planet) is to be calculated from the (planet's) own ascensional difference, etc., as taught in connection with the Moon's rising.

In the case of conjunction of the planets (i.e., occultation of one planet by another), the *lambana* and *nati* are prescribed to be found out (by proportion) from the (planets') own "dividing numbers". The remaining processes such as the calculation of the *sthityardha* (i.e., the semi-duration of occultation) are the same as in the case of a (solar) eclipse.

Concluding stanzas :

61-62. The predictions of those (astronomers) whose minds are purified by day to day practice and who have acquired by the grace of the teacher the eye of true conception of the astronomical science, (always) agree with the planetary phenomena and do not go astray as the pure thoughts (desires) of a lovely and devoted wife (do not go astray).

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[1] The same rule occurs in *ŚiDVṛ*, *I*, x. 4.

CHAPTER VII

# ASTRONOMICAL CONSTANTS

Revolutions performed by the planets around the Earth in a period of 43,20,000 solar years (called a *yuga*) :

1-5. The revolution-number (*bhagaṇa*) of the Sun is 43,20,000 ; of the Moon, 5,77,53,336 ; of Saturn, 1,46,564 ; of Jupiter, 3,64,224 ; of Mars, 22,96,824 ; of Mercury and Venus and of the *śīghroccas* of the other planets, the same as that of the Sun; of the Moon's apogee, 4,88,219 ; of (the *śīghrocca* of) Mercury, 1,79,37,020 ; of (the *śīghrocca* of) Venus, 70,22,388 ; and of the Moon's ascending node, 2,32,226.

Intercalary months, omitted lunar days, and civil days in a *yuga* :

6-8. The number of intercalary months (in a *yuga*) is 15,93,336. For the determination of the number of intercalary months elapsed, (this is the multiplier) : the diviser is twelve times the number of solar years in a *yuga* (i.e., 5,18,40,000). The number of omitted lunar days (in a *yuga*) is 2,50,82,580. (For finding the number of omitted lunar days elapsed, this is the multiplier) : the divisor is 1,60,30,00,080 (which is the number of lunar days in a *yuga*). The number of civil days in a *yuga* is stated to be 1,57,79,17,500.

Intercalary months in a *yuga*

= (lunar months in a *yuga*) — (solar months in a *yuga*)
= { (revolution-number of the Moon) — (revolution-number of the Sun) } — 12 × (revolution-number of the Sun)
= (revolution-number of the Moon) — 13 × (revolution-number of the Sun)
= 15,93,336.

Omitted lunar days in a *yuga*

= (lunar days in a *yuga*) — (civil days in a *yuga*)
= 2,50,82,580.

Inclinations of the orbits of the planets to the ecliptic :

9. The degrees of the greatest celestial latitudes of Mercury, Venus, and Saturn are each 2 ; of Jupiter, 1 ; and of Mars, $1\frac{1}{2}$.[1]

Longitudes of the ascending nodes of the planets and a rule for finding the celestial latitude of a planet :

10. The degrees of the longitudes of the ascending nodes (of the same planets) are 20, 60, 100, 80, and 40 respectively.[2] The celestial latitude, north or south, (of a planet) should be given out after calculation from the longitude of the planet minus the longitude of its ascending node.

Longitudes of the apogees of the planets and the method for finding the *manda* and *śīghra* anomalies :

11-12. The degrees of the longitudes of the apogees (of the same planets) are respectively 210, 90, 236, 180, and 118. Of the Sun they are to be known as 78.[3]

(In order to get the *manda* anomaly) subtract the longitude of the apogee (of the planet) from the longitude of the planet ; and (in order to obtain the *śīghra* anomaly) always subtract the longitude of the planet from the longitude of the *śīghrocca* (of the planet).

*Manda* and *śīghra* epicycles of the planets, and Rsine-differences corresponding to the twenty-four elements of a quadrant ;

13-16. In (the beginnings of) the odd quadrants the *manda* and *śīghra* epicycles (of Mercury, Venus, Saturn, Jupiter, and Mars) are 7, 4, 9, 7, 14 and 31, 59, 9, 16, 53 (respectively) ; and in (the beginnings of) the even quadrants they are stated to be 5, 2, 13, 8, 18 and 29, 57, 8, 15, 51 (respectively). Of the Sun and the Moon, the epicycles are 3 and 7 (respectively).

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[1] The same values are found in *Ā*, i. 8 and *ŚiDVṛ*, *I*, x. 5(i).

[2] The same longitudes are given in *Ā*, i. 9(i) and *ŚiDVṛ*, *I*, x. 5(ii).

[3] These longitudes are the same as found in *Ā*, i. 9(ii) and *ŚiDVṛ*, *I*, ii. 28(i), 9(iv).

The Rsine-differences (corresponding to the twenty-four elements of a quadrant) are 225 (*makhi*), etc. (as stated by Āryabhaṭa I).[2]

The dimensions of the epicycles have been stated after dividing them by $4\frac{1}{2}$. They are the same as given by Āryabhaṭa I. In fact all the astronomical constants stated in the above stanzas are the same as found in the Āryabhaṭīya.

It must be pointed out that, according to Bhāskara I, the *manda* and *śīghra* epicycles stated above from the *Āryabhaṭīya* of Āryabhaṭa I, correspond to the beginnings of the respective quadrants as is evident from the rule stated in *MBh*, iv. 38-39(i) and *LBh*, ii. 31-32 and explained in Bhāskara I's commentary on *Ā*, iii. 22. Govinda Svāmī, however, is of opinion that the *śīghra* epicycles stated by Āryabhaṭa I correspond to the beginnings of the respective quadrants, but the *manda* epicycles stated by Āryabhaṭa I, correspond to the endings of the respective quadrants.[3] Consequently, he has replaced the rule referred to above by another rule which has been quoted by Udaya-divākara in his commentary on *LBh*, ii. 31-32. This controversy is due to the fact that Āryabhaṭa I himself does not say whether the epicycles given by him correspond to the beginnings or endings of the quadrants.

A rule for finding the *bāhuphala* and *koṭiphala*, etc., without the use of the Rsine-difference table :

17-19. (Now) I briefly state the rule (for finding the *bhujaphala* and *koṭiphala* etc.) without making use of the Rsine-differences, 225, etc.

Subtract the degrees of the *bhuja* (or *koṭi*) from the degrees of half a circle (i.e., 180°). Then multiply the remainder by the degrees of the *bhuja* (or *koṭi*) and put down the result at two places. At one place subtract the result from 40500. By one-fourth of the remainder (thus obtained) divide the result

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[2] For the table of Rsine-differences referred to here, see *supra*, p. 108.

[3] See Govinda Svāmī's comm. on *MBh*, iv. 38-39(i).

at the other place as multiplied by the *antyaphala* (i.e., the epicyclic radius)[1]. Thus is obtained the entire *bāhuphala* (or *koṭiphala*) for the Sun, Moon, or the star-planets. So also are obtained the direct and inverse Rsines.[2]

This rule is based on the formula:

$$\sin\theta = 4(180-\theta)\theta/\{40500-(180-\theta)\theta\},$$

where $\theta$ is in degrees.

The following is a *rationale* of this approximate formula : In Fig. 24, let CA be the diameter of a circle of radius R, where arc AB is equal to $\theta$ degrees and BD = Rsin $\theta$. Then

$$\text{Area ABC} = \tfrac{1}{2}\,\text{AB. BC.}$$

$$\text{Also area ABC} = \tfrac{1}{2}\,\text{AC. BD.}$$

Therefore,

$$\frac{1}{\text{BD}} = \frac{\text{AC}}{\text{AB. BC}},$$

so that

$$\frac{1}{\text{BD}} > \frac{\text{AC}}{(\text{arc AB})\times(\text{arc BC})}.$$

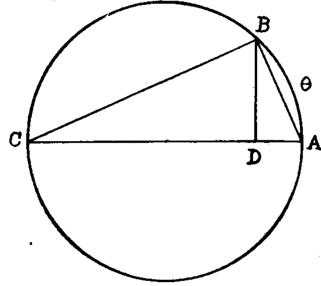


Fig. 24

Let

$$\frac{1}{\text{BD}} = \frac{x.\,\text{AC}}{(\text{arc AB})\times(\text{arc BC})} + y$$

$$= \frac{2\,x\text{R}}{\theta\,(180-\theta)} + y,$$

$$\text{so that Rsin}\,\theta = \frac{\theta\,(180-\theta)}{2x\text{R} + \theta\,(180-\theta)\,y}. \qquad (1)$$

Putting $\theta = 30°$,

$$\tfrac{1}{2}\,\text{R} = \frac{30\times150}{2x\text{R}+30\times150\,y},$$

$$\text{i.e., } 2x\text{R} + 4500\,y = \frac{9000}{\text{R}}. \qquad (2)$$

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[1] इष्टोच्चनीचव्यासार्धं परमफलजीवा । *BrSpSi*, xiv. 24(ii).

[2] *Cf. BrSpSi*, xiv. 23-24; *SiŚe*, iii. 17.

Putting $\theta=90°$,

$$2x\mathrm{R}+8100y=\frac{8100}{\mathrm{R}}. \tag{3}$$

From (2) and (3),

$$y=-\frac{1}{4\mathrm{R}},$$

$$\text{and} \quad 2x\mathrm{R}=\frac{40500}{4\mathrm{R}}.$$

Therefore, from (1)

$$\mathrm{R}\sin\theta=\frac{4\theta(180-\theta)\mathrm{R}}{40500-\theta(180-\theta)}.$$

The same result may also be derived as follows:
Let

$$\sin\lambda=\frac{a+b\lambda+c\lambda^2}{A+B\lambda+C\lambda^2},$$

where $\lambda$ is in radians and corresponds to $\theta$ degrees.

Putting $\lambda=0$, $a=0$.

Putting $\lambda=\pi$, $b+\pi c=0$. Therefore, $c=-\frac{b}{\pi}$.

Thus

$$\sin\lambda=\frac{b\lambda(\pi-\lambda)/\pi}{A+B\lambda+C\lambda^2}.$$

Since $\sin\lambda=\sin(\pi-\lambda)$, therefore

$$\frac{b\lambda(\pi-\lambda)/\pi}{A+B\lambda+C\lambda^2}=\frac{b\lambda(\pi-\lambda)/\pi}{A+B(\pi-\lambda)+C(\pi-\lambda)^2}.$$

or $$A+B\lambda+C\lambda^2=A+B(\pi-\lambda)+C(\pi-\lambda)^2,$$

or $$B(2\lambda-\pi)=C\pi(\pi-2\lambda),$$

giving $$C=-\frac{B}{\pi}.$$

Therefore, $$\sin\lambda=\frac{b\lambda(\pi-\lambda)}{A\pi+B\lambda(\pi-\lambda)}.$$

Putting in this $\lambda=\frac{1}{6}\pi$,

$$A\pi+B\tfrac{1}{6}\pi(\pi-\tfrac{1}{6}\pi)=2b.\ \tfrac{1}{6}\pi(\pi-\tfrac{1}{6}\pi),$$

$$\text{or} \quad A\pi+\frac{5\pi^2B}{36}=\frac{10\pi^2b}{36}. \tag{4}$$

Also putting $\lambda=\frac{1}{2}\pi$,

$$A\pi + B.\tfrac{1}{2}\pi(\pi-\tfrac{1}{2}\pi)=b.\tfrac{1}{2}\pi(\pi-\tfrac{1}{2}\pi),$$
$$\text{or } A\pi + \tfrac{1}{4}\pi^2 B=\tfrac{1}{4}\pi^2 b. \qquad (5)$$

From (4) and (5),

$$B = -\tfrac{1}{4}b,$$
$$\text{and } A = \frac{5\pi b}{16}.$$

Therefore,

$$\sin\lambda = \frac{16\lambda(\pi-\lambda)}{5\pi^2 - 4\lambda(\pi-\lambda)},$$

where $\lambda = \pi\theta/180$.

The length of the so called circle of the sky and the rule for deriving the length of the orbit of a planet:

20. Multiply the revolution-number of the Moon by 216000: then is obtained the length of the circle of the sky (in terms of *yojanas*). When the circle of the sky is divided by the revolution-number of any given planet, the quotient denotes the length of the circular orbit of that planet.

Thus we get

(1) length of the circle of the sky $=$ 1,24,74,72,05,76,000 *yojanas*,

(2) length of the Sun's orbit $=$ 28,87,666 $\frac{4}{5}$ *yojanas*,

(3) length of the Moon's orbit $=$ 2,16,000 *yojanas*,

(4) length of Mars' orbit $=$ 54,31,291 $\frac{132027}{287103}$ *yojanas*,

(5) length of Mercury's orbit $=$ 6,95,473 $\frac{373277}{896851}$ *yojanas*,

(6) length of Jupiter's orbit $=$ 3,42,50,133 $\frac{699}{1897}$ *yojanas*,

(7) length of Venus's orbit $=$ 17,76,421 $\frac{255221}{585199}$ *yojanas*,

(8) length of Saturn's orbit $=$ 8,51,14,493 $\frac{5987}{36641}$ *yojanas*.

Midnight day-reckoning of Āryabhaṭa I:

21. The astronomical processes which have been set forth above come under the sunrise day-reckoning. In the midnight

day-reckoning too, all this is found to occur: the difference that exists is being stated (below).

The next fourteen stanzas relate to the midnight day-reckoning of Āryabhaṭa I.

Civil days and omitted lunar days in a *yuga* and revolution-numbers of Mercury and Jupiter:

22. (To get the corresponding elements of the midnight day-reckoning) add 300 to the number of civil days (in a *yuga*) and subtract the same (number) from the number of omitted lunar days (in a *yuga*); and from the revolution-numbers of (the *śīghrocca* of) Mercury and Jupiter subtract 20 and 4 respectively.

Thus according to the midnight day-reckoning,

civil days in a *yuga* = 1,57,79,17,800,
omitted lunar days in a *yuga* = 2,50,82,280,
revolution-number of the *śīghrocca* of Mercury = 1,79,37,000,
revolution-number of Jupiter = 3,64,220.

Diameters of the Earth, the Sun, and the Moon:

23. (In the midnight day-reckoning) the diameter of the Earth is (stated to be) 1600 *yojanas*; of the Sun, 6480 (*yojanas*); and of the Moon, 480 (*yojanas*).

Mean distances of the Sun and the Moon:

24. The (mean) distance of the Sun is stated to be 689358 (*yojanas*); and of the Moon, 51566 (*yojanas*).

Longitudes of the apogees of the planets:

25. 160, 80, 240, 110, and 220 are in degrees the longitudes of the apogees of Jupiter, Venus, Saturn, Mars, and Mercury respectively [1].

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[1] *Cf. KK* (Sengupta's edition), ii. 6(i).

*Manda* and *śighra* epicycles of the planets:

26-28(i). The *manda* epicycles (of the same planets) are 32, 14, 60, 70, and 28 (degrees) respectively; and the *śighra* epicycles are 72, 260, 40, 234, and 132 (degrees) respectively. The Sun's apogee and epicycle are the same as those of Venus (i.e., 80° and 14° respectively). The Moon's epicycle in the midnight day-reckoning is stated to be 31 (degrees).

Positions of the so called *manda* and *śighra pātas* of the planets:

28(ii)-31(i). (The following directions for) the degrees of the (*manda* and *śighra*) *pātas* of the planets as devised (under the midnight day-reckoning) should be noted carefully by learned scholars.

Add 180° to the longitudes of the *mandoccas* (apogees) and *śighroccas* of Mercury and Venus, and subtract 3 signs from the *mandoccas* (apogees) and *śighroccas* of the remaining planets. Then are obtained the longitudes of the *manda* and *śighra pātas* of the planets. (Also) add 2 degrees to the longitudes of the *manda pātas* and *śighroccas* of Venus, Saturn, and Jupiter; and 1½ degrees to those of Mars and Mercury. (It should be noted that) the *śighra pātas* have been stated for all the planets excepting Mercury. (Mercury does not have a *śighra pāta*).[1]

That is to say, the longitudes of the *manda-pātas* of Mars, Mercury, Jupiter, Venus, and Saturn are 21°·5, 41°·5, 72°, 262°, and 152° respectively; and the longitudes of the *śighra-pātas* of Mars, Jupiter, Venus, and Saturn are (*śighrocca* — 88°·5), (*śighrocca* — 88°), (*śighrocca* + 182°) and (*śighrocca* — 88°) respectively.

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[1] This passage represents rather old ideas of Hindu astronomy. The conception of *manda* and *śighra pātas* does not occur in any other work. Our translation agrees with the interpretations given in the various commentaries. The translation given by P. C. Sengupta in the introduction to his *Khaṇḍa-khādyaka* is wrong.

A rule for finding the celestial latitude of a planet :

31(ii)-33. (From the longitude of a planet severally) subtract the longitudes of its (*manda* and *śīghra*) *pātas*, and therefrom calculate (as usual) the corresponding celestial latitudes of that planet. Add them or take their difference according as they are of like or unlike directions. Then is obtained the true celestial latitude of that particular planet. The true celestial latitude of any other planet is also obtained in the same way. The remaining (astronomical) determinations are the same as stated before. This all is in brief the difference of the other *tantra* (embodying the midnight day-reckoning of Āryabhaṭa I).

A rule for finding the longitude of the true-mean planet according to the midnight day-reckoning :

34. Apply half the *śīghraphala* and (then) half the *mandaphala* to the longitude of the planet's own *mandocca* (reversely). From the resulting longitude of the planet's *mandocca* calculate (the *mandaphala* and apply it to the the mean longitude of the planet: the resulting longitude of planet is stated to be) the true-mean longitude of the planet. This is stated to be another difference (of the midnight day-reckoning).[1]

Length of the circle of the sky and derivation of the lengths of the orbits of the planets :

35. Multiply the revolutions of the Moon (in a *yuga*) by 32,40,000 and then discard the zero in the unit's place : (this is the length of the circle of the sky in terms of *yojanas*). (Severally) divide that by the revolutions of the planets (in a *yuga*): thus are obtained the lengths of the orbits of the respective planets in terms of *yojanas*.

From stanzas 20 and 35 it is evident that one *yojana* of the sunrise day-reckoning is one and a half times that of the midnight day-reckoning.

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[1] This rule is the same as found in *PSi*, xvii. 4-9 ; *SūSi*, ii, 44 ; *MSi*, iii. 28 ; and *SiTV*, ii. 247.

CHAPTER VIII

# EXAMPLES

(Solved Examples)

To find the true lunar day (*tithi*) and the *ghaṭīs* elapsed at sunrise since the beginning of the current lunar day without the knowledge of the true longitudes of the Sun and Moon:

1-4. Multiply the *ahargaṇa* by the number of lunar years[1] (in a *yuga*) and divide by the number of civil days[2] (in a *yuga*). Then are obtained the mean lunar years, etc. (corresponding to the *ahargaṇa*). Also multiply the *ahargaṇa* by the number of intercalary lunar years[3] (in a *yuga*) and divide by the number of civil days[2] (in a *yuga*). (Thus are obtained the mean intercalary years, etc., corresponding to the *ahargaṇa*). The difference between the two denotes the (mean) solar years, etc. (i.e., years, months, days, and *ghaṭīs*) (corresponding to the *ahargaṇa*).

The solar years are not required (so they are to be omitted). From the remaining quantity (in months, days, and *ghaṭīs*) subtract two months and eighteen days. Then (treating the months, days, etc., of the remainder thus obtained as the signs, degrees, etc., of the Sun's mean anomaly) calculate the (Sun's) equation of the centre.

Divide the (corresponding) solar time by 12 and apply that to the (mean) lunar days (and *ghaṭīs*) (obtained from the *ahargaṇa*) contrarily (i.e., add when the Sun's equation of the centre is subtractive and subtract when the Sun's equation of the centre is additive). Also apply one-twelfth of the time corres-

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[1] i.e., 44,52,778.

[2] i.e., 1,57,79,17,500.

[3] i.e., 1,32,778.

ponding to the Moon's equation of the centre[1] to the resulting lunar days (and *ghaṭīs*) in the same way as it is applied to the Moon's longitude.

(The lunar days thus obtained are the true lunar days which have elapsed at sunrise since the beginning of the current month). The *ghaṭīs* obtained above denote the elapsed portion of the current lunar day in terms of *ghaṭīs*. Multiply those *ghaṭīs* by 60 and divide by one-twelfth of the difference between the true daily motions of the Sun and Moon, in degrees: the quotient denotes the true time in *ghaṭīs* (which has elapsed at sunrise since the beginning of the current lunar day).[2]

Let the mean lunar years, etc., elapsed at sunrise be $a$ years, $b$ months, $c$ days, and $d$ *ghaṭīs*; and let the mean intercalary years, etc., elapsed at sunrise be $a'$ years, $b'$ months, $c'$ days, and $d'$ *ghaṭīs*. Then the mean solar years, etc., elapsed at sunrise are $(a-a')$ years, $(b-b')$ months, $(c-c')$ days, and $(d-d')$ *ghaṭīs*.

The mean longitude of the Sun is therefore equal to $(a-a')$ revolutions, $(b-b')$ signs, $(c-c')$ degrees, and $(d-d')$ minutes. The longitude of the Sun's apogee being 2°18′, the Sun's mean anomaly is equal to $(b-b')$ signs, $(c-c'-2)$ degrees, and $(d-d'-18)$ minutes.

Suppose that the Sun's equation of the centre derived from the above Sun's mean anomaly is $m$ minutes. Then we subtract $m/12$ *ghaṭīs* from or add the same amount to $c$ days and $d$ *ghaṭīs* obtained above, according as the Sun's equation of the centre is additive or subtractive. Thus we get $c$ days and $(d \mp m/12)$ *ghaṭīs*.

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[1] To obtain the Moon's equation of the centre, the mean longitude of the Moon may be obtained as follows: Multiply the mean lunar days, etc., (corresponding to the *ahargaṇa*) by 12, convert the resulting days etc. into months, etc., and add to them the mean solar months, etc., (corresponding to the *ahargaṇa*); treat the months, etc., thus obtained as the signs, etc., of the mean longitude of the Moon.

[2] A similar rule occurs in *BrSpSi*, xiii. 23-25 and *SiŚe*, iii. 72-74.

Also suppose that the Moon's equation of the centre is $n$ minutes. Then we add $n/12$ *ghaṭīs* to or subtract the same from $c$ days and $(d \mp m/12)$ *ghaṭīs*. Thus we obtain

$c$ days, $(d \mp m/12 \pm n/12)$ *ghaṭīs*.

$c$ days in this result shows that $c$ complete true lunar days have elapsed at sunrise; and $(d \mp m/12 \pm n/12)$ *ghaṭīs* shows that part of the current lunar day amounting to so many *ghaṭīs* has also elapsed at sunrise.

Multiplying $(d \mp m/12 \pm n/12)$ by 60 and dividing the product by 1/12 of the degrees of difference between the true daily motions of the Sun and Moon are obtained the *ghaṭīs* elapsed at sunrise since the beginning of the current lunar day.

The following is the *rationale* of the above rule:

True lunar day (*tithi*)

= (true longitude of the Moon—true longitude of the Sun)/12.

= {(mean longitude of the Moon ± Moon's equation of the centre)—(mean longitude of the Sun ±Sun's equation of the centre)}/12.

= {(mean longitude of the Moon — mean longitude of the Sun) ∓ (Sun's equation of the centre) ± (Moon's equation of the centre)}/12.

$$= \frac{\textit{ahargaṇa} \times (\text{Moon's rev.-number—Sun's rev.-number})^{1}}{\text{civil days in a } \textit{yuga} \times 12}$$

∓ (Sun's equation of the centre)/12

± (Moon's equation of the centre)/12

$$= \frac{\textit{ahargaṇa} \times (\text{lunar years in a } \textit{yuga})}{\text{civil days in a } \textit{yuga}}$$

∓ (Sun's equation of the centre)/12

± (Moon's equation of the centre)/12

= mean lunar years, etc., elapsed at sunrise

∓ (Sun's equation of the centre)/12

± (Moon's equation of the centre)/12.

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[1] Rev.-number denotes revolution-number,

= mean lunar days and *ghaṭīs* elapsed at sunrise
$\mp$ (Sun's equation of the centre)/12
$\pm$ (Moon's equation of the centre)/12,

where the signs are chosen appropriately. Lunar months and years are discarded as they are not required.

To obtain the Sun's mean longitude from the Sun's true longitude derived from the midday shadow of the gnomon:

5. Subtract the longitude of the Sun's apogee from the Sun's true longitude derived from the midday shadow (of the gnomon) and (then treating the remainder as the Sun's mean anomaly) calculate the Sun's equation of the centre. Apply that (equation of the centre) to the Sun's true longitude contrarily to the usual law for its subtraction and addition. (Treating this result as the mean longitude of the Sun, calculate the Sun's equation of the centre afresh and apply that to the Sun's true longitude as before.) Repeat the same process again and again (until two successive results agree to minutes). Thus is obtained the mean longitude of the Sun.[1]

The method used here is evidently the method of successive approximations.

To find the arc corresponding to a given Rsine:

6. From the given Rsine subtract in serial order (as many tabulated Rsine-differences as possible): multiply the number of the Rsine-differences subtracted by 225. Then multiply the residue (of the given Rsine) by 225 and divide by the current Rsine-difference.[2] Add this result to the previous one. Thus is obtained the arc (corresponding to the given Rsine in terms of minutes).[3]

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[1] This rule occurs also in *BrSpSi*, xiv. 28; iii. 61-62; *SiŚi, I*, ii. 45.

[2] i.e., the tabulated Rsine-difference which is next to those subtracted.

[3] This rule is found also in *SūSi*, ii. 33; *BrSpSi*, ii. 11; *ŚIDVṛ, I*, ii. 13; *SiŚe*, iii. 16; *SiŚi, I*, ii. 11(ii)-12(i).

This rule is the converse of that stated in chapter IV, stanzas 3-4(i).

## EXAMPLES

Six examples on the shadow of the gnomon :

7. The latitude (of a place) is one and a half degrees minus eight minutes (i.e., $1^\circ 22'$); and the midday shadow of the gnomon of 12 *aṅgulas* on level ground is 5 *aṅgulas*. Give out the sun's longitude at noon on that day.[1]

8. Quickly say the longitude of the meridian Sun for the place where the latitude is stated to be 8 degrees minus 16 minutes (i. e., $7^\circ 44'$) and the midday shadow of the gnomon, 3 and a half (*aṅgulas*).

9. Quickly say the true longitudes of the Sun for the places where the latitudes are stated to be 25 and 30 degrees respectively and the lengths of the midday shadows (of the gnomon) are equal to the gnomon (itself).

10. Say what is the longitude of the Sun at the place where the latitude is 15 degrees and the prime vertical shadow of (the gnomon due to) the Sun, one and a half *aṅgulas* together with one-fifth of an *aṅgula* (i.e., 17/10 *aṅgulas*).[2]

11. The prime vertical shadow (of the gnomon) is 37 *aṅgulas* and the equinoctial midday shadow is 30 *aṅgulas*. Say the longitude of the universal lamp, the Sun, for its position on the prime vertical.

12. The east-west shadow (of the gnomon) is seen on level ground to be 16 (*aṅgulas*). The latitude of the place is seven and a half degrees. Say what is the Sun's longitude there.

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[1] The examples set in this and the next two stanzas are based on the rules stated before in chapter III, stanzas 5 and 13-15.

[2] The examples set in this and the next two stanzas are based on the rules given before in chapter III, stanzas 5 and 41.

Eleven examples on the pulveriser (*kuttākāra*) :

13. The signs, etc., up to the thirds of the Sun's (mean) longitude have all been carried away by the strong wind; the residue of thirds is known to me to be 101. Tell (me) the Sun's (mean) longitude and also the *ahargaṇa*.[1]

14. The minutes together with the signs and degrees of the Moon's (mean) longitude have been destroyed being rubbed out by the hands of a child; twenty-five seconds are seen to remain (undestroyed). Calculate from them, O you of noble descent, the *ahargaṇa* and the (mean) longitude of the Moon.

The following is the solution of this example :

$$\frac{\text{Revolution-number of the Moon reduced to minutes}}{\text{civil days in a } yuga} = \frac{68167872}{86225}.$$

Multiplying 25 by 86225 and dividing the product by 60, the quotient is 35927. This is the residue of the minutes (*Kalāśeṣa*).[2] We have, therefore, to solve the pulveriser

$$\frac{68167872\,x - 35927}{86225} = y,$$

where $x$ denotes the required *ahargaṇa* and $y$ the Moon's mean longitude in terms of minutes.

By the usual process[3], we get

$$x = 70091,$$
$$y = 55412633'.$$

Hence the required *ahargaṇa* = 70091 days, and the Moon's mean longitude = 4 signs 23° 53′ 25″.

15. The signs and degrees (of the mean longitude of Mars) have been carried away by the hurricane; the residue of the

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[1] Answer : *Ahargaṇa* = 106141; Sun's mean longitude = 3 signs 32° 52′23″11‴. For complete solution see *supra*, pp. 35-36.

[2] *Vide supra*, chapter I, stanza 46(ii), p. 33.

[3] *Vide supra*, chapter I, stanzas 42-44, p. 30.

degrees is 73. Say what is the (mean) longitude of Mars and also what is the *ahargaṇa*.

The following is the solution of this example:

$$\frac{\text{Revolution-number of Mars reduced to degrees}}{\text{civil days in a } yuga} = \frac{13780944}{26298625}.$$

The pulveriser to be solved is therefore

$$\frac{13780944x - 73}{26298625} = y,$$

where $x$ denotes the required *ahargaṇa* and $y$ the mean longitude of Mars in terms of degrees.

Solving the pulveriser by the usual process, we get

$$x = 17420617$$
$$y = 9128711.$$

Hence the required *ahargaṇa*=17420617 days, and the mean longitude of Mars=9128711°, i.e., 25357 revs., 6 signs, 11 degrees.

16. The (mean) longitude of Mercury is 3 signs, 15 degrees, and 5 minutes. Considering this give out the days elapsed (i.e., the *ahargaṇa*) and also the revolutions performed by him.

The following is the solution of this example:

Longitude of Mercury= 3 signs 15° 5′
= 6305′.

Now

$$\frac{\text{revolution-number of Mercury}}{\text{civil days in a } yuga} = \frac{896851}{78895875}.$$

Therefore multiplying 6305 by 78895875 and then dividing the product by 21600, we get 23029559 as the quotient. This is the residue of the revolutions. Thus we have to solve the pulveriser

$$\frac{896851x - 23029559}{78895875} = y,$$

where $x$ denotes the *ahargaṇa* and $y$ the required revolutions.

By the usual method, we get $x = 74350409$ and $y = 845180$.

17. The signs, degrees, and minutes of the (mean) longitude of Jupiter have been destroyed by a mischievous child; nine seconds are seen to remain (undisturbed). Say therefrom the *ahargaṇa* and the mean longitude of Jupiter.

The following is the solution of this example:

$$\frac{\text{Revolution-number of Jupiter reduced to minutes}}{\text{civil days in a } yuga} = \frac{26224128}{5259725}$$

Multiplying 9 by 5259725 and dividing the product by 60, we obtain 788958 as the quotient. This is the residue of the minutes. Then we have to solve the pulveriser

$$\frac{26224128x - 788958}{5259725} = y,$$

where $x$ denotes the *ahargaṇa* and $y$ the longitude of Jupiter in terms of minutes.

Solving the pulveriser, we get $x = 2269811$, $y = 11316906'$, *i. e.*, 523 revs., 11 signs, 5 degrees, 6 minutes. The required *ahargaṇa* is therefore 2269811 days, and the mean longitude of Jupiter is 11 signs $5° \, 6' \, 9''$.

18. The revolutions, etc., up to the minutes of the (mean) longitude of Venus are destroyed; 10 seconds are seen to remain intact. Of Saturn, 17 seconds are found to remain intact. Quickly say (the mean longitudes of) them and also the *ahargaṇa* (in the two cases).

The following is the solution of this example:

$$\frac{\text{Revolution-number of Venus reduced to minutes}}{\text{civil days in a } yuga} = \frac{505611936}{5259725}.$$

Multiplying 10 by 5259725 and dividing the product by 60, the quotient is 876620: this is the residue of the minutes. The resulting pulveriser is

$$\frac{505611936\,x - 876620}{5259725} = y,$$

where $x$ is the *ahargaṇa* and $y$ the corresponding longitude of Venus in

minutes. Solving this pulveriser, we get $x = 4081170$, $y = 392318660$. Hence the *ahargaṇa*=4081170 days, and the corresponding mean longitude of Venus = 10 signs 24° 20′ 10″.

Again

$$\frac{\text{revolution-number of Saturn reduced to minutes}}{\text{civil days in a } yuga} = \frac{10552608}{5259725}$$

Multiplying 17 by 5259725 and dividing the product by 60, the quotient is 1490255: this is the residue of the minutes. The resulting pulveriser is

$$\frac{10552608\,x - 1490255}{5259725} = y,$$

where $x$ denotes the *ahargaṇa* and $y$ the mean longitude of Saturn in minutes. Solving this pulveriser, we get $x = 3308510$, $y = 6637877$. Hence the required *ahargaṇa* = 3308510, and the mean longitude of Saturn = 3 signs 21° 17′ 17″.

19. The sum of the (mean) longitudes of Mars and the Moon is calculated to be 5 signs, 7 degrees, and 9 minutes. O you, well versed in the (*Ārya*)*bhaṭa-tantra*, quickly say the *ahargaṇa* and also the (mean) longitudes of the Moon and Mars.[1]

The following is the solution of this example:

Mean longitude of Mars + mean longitude of the Moon = 5 signs 7° 9′ = 9429′.

Also

$$\frac{\text{sum of the revolution-numbers of Mars and the Moon}}{\text{civil days in a } yuga} = \frac{1000836}{26298625}.$$

Multiplying 9429 by 26298625 and dividing the product by 21600, the quotient is 11480080: this is the residue of the revolutions. We have therefore to solve the pulveriser

$$\frac{1000836\,x - 11480080}{26298625} = y,$$

where $x$ is the required *ahargaṇa*. Solving the pulveriser, we get $x = 5646655$. From this *ahargaṇa* we can easily calculate the mean longitudes of Mars and the Moon.

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1 For Govinda Svāmi's modification of this example, see *supra*, chapter I, under stanza 52.

20. The difference between the mean longitudes of Mars and Jupiter is exactly 5 signs. Say what is the number of days elapsed since the beginning of Kaliyuga and what are the (mean) longitudes of Jupiter and Mars.[1]

21-22. The Sun and Moon on a Sunday at sunrise are carefully seen by me in (the sign) Libra. The degrees of their (mean) longitudes are 12 and 2 respectively; the minutes are 1 and 40 respectively. After how many days will they assume the same longitudes again (at sunrise) on a Thursday, Friday, and Saturday respectively? (It is also given that) the (mean) longitude of the Sun is in excess by 17 seconds (over that given above); whereas from the (mean) longitude of the Moon (given above 18 seconds have to be subtracted.[2]

That is to say,

the Sun's longitude=6 signs, 12 degrees, 1 minute, and 17 seconds; and the Moon's longitude=6 signs, 2 degrees, 39 minutes, and 42 seconds.

Calculation will show that the Sun and Moon assume these longitudes on a Sunday 7500 days after the commencement of Kaliyuga.

The problem now is to find out the *ahargaṇas* when the Sun and Moon again assume the same longitudes at sunrise on a Thursday, Friday, and Saturday respectively. This is done as follows:

**(i) Ahargaṇa for Thursday.** Let the corresponding *ahargaṇa* be $7500 + A$. Obviously, in $A$ days the Sun and Moon will describe complete revolutions. Also since Thursday is four days in advance of Sunday, therefore $A-4$ will be perfectly divisible by seven. In other words,

$$\frac{576A}{210389},\ \frac{78898A}{2155625},\ \text{and}\ \frac{A-4}{7}$$

will be whole numbers. If we assume $A = 131493125X$,[3] the first two

[1] This example has been solved in chapter I under stanza 52. See *supra*, p. 44.

[2] Bhāskara I's example, occurring in his comm. on *A*, ii. 32-33.

[3] This number is the L.C.M. of 210389 and 2155625.

fractions will obviously be whole numbers, and we have only to make $(131493125X-4)/7$ a whole number. Let

$$\frac{131493125X-4}{7} = Y,$$

or $$\frac{X-4}{7} = Z, \text{ where } Y = 18784732X+Z.$$

Solving this equation, we find that $X = 4$ makes $(131493125X-4)/7$ a whole number. Therefore, the required *ahargaṇa*

$$= 7500+A$$
$$= 7500+131493125X$$
$$= 7500+131493125\times4$$
$$= 525980000 \text{ days.}$$

**(ii) Ahargaṇa for Friday.** In this case, the required *ahargaṇa* is obviously equal to $7500+131493125\times5$, i.e., 657473125 days.

**(iii) Ahargaṇa for Saturday.** In this case, the required *ahargaṇa* = $7500+131493125\times6 = 788966250$ days.

23. The revolutions, etc., of the Sun's (mean) longitude, calculated from an *ahargaṇa* plus a few *nāḍīs* elapsed, have now been destroyed by the wind; 71 minutes are seen by me to remain intact. Say the *ahargaṇa*, the sun's (mean) longitude, and the correct value of the *nāḍīs* (used in the calculation).[1]

24·24*. Some number of days is (severally) divided by the (abraded) civil days for the Sun and for Mars. The (resulting) quotients are unknown to me; the residues, too, are not seen by me. The quotients obtained by multiplying those residues by the respective (abraded) revolution-numbers and then dividing (the products) by the respective (abraded) civil days are also blown away by the wind. The remainders of the two (divisions) now exist. The remainder for the Sun is 38472; that for Mars, 77180625. From these remainders severally

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[1] This example has been solved in Chapter I under stanza 49. See *supra*, p. 40.

calculate, O mathematician, the *ahargaṇas* for the Sun and Mars and also the *ahargaṇa* conforming to the two residues and state them in proper order.[1]

One example on the determination of the latitude :

25. The Sun being at the end of (the sign) Gemini, the length of the night is 21 *ghaṭīs*. Calculate and give out the latitude and also the colatitude of the place.[2]

Authorship and appreciation of the work :

26. This *Āryabhaṭa-karma-nibandha* ("a compendium of astronomical processes based on the teachings of Āryabhaṭa I"), which has clear expressions and simple methods (of calculation) and which can be comprehended even by those with lesser intellect, is written by Bhāskara after full deliberation.

27. Whatever occurs in this work regarding the projection and calculation of solar eclipses (etcetra), which are dealt with by giving numerous rules with clear meaning, also finds place elsewhere; and what does not find place here does not occur anywhere else.

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[1] This example has been solved in Chapter I under stanza 52. See *supra*, p. 45-46.

[2] Assuming the obliquity of the ecliptic to be 23°30′, the required latitude comes out to be 61°45′ approx.

## QUOTATIONS

### from the *Mahā-Bhāskarīya* in Later Works

Passages from the *Mahā-Bhāskarīya* occur as quotations in the following commentaries:

(1) Śaṅkaranārāyaṇa's commentary (869 A. D.) on the *Laghu-Bhāskarīya*.

(2) Udayadivākara's commentary (1073 A. D.) on the *Laghu-Bhāskarīya*.

(3) Sūryadeva's commentaries on the *Āryabhaṭīya* and the *Laghu-mānasa*.

(4) Makkibhaṭṭa's commentary (1377 A. D.) on the *Siddhānta-śekhara*.

(5) Parameśvara's commentary (1408 A. D.) on the *Laghu-Bhāskarīya*.

(6) Nīlakaṇṭha's commentary (c. 1500 A. D.) on the *Āryabhaṭīya*.

(7) Govinda Somayājī's commentary, entitled *Daśādhyāyī*, on the *Bṛhajjātaka* of Varāhamihira.

(8) Viṣṇu Śarmā's commentary (c. 1363) on the *Vidyā-mādhavīya*.

Below we refer to these passages and to the places where they occur as quotations.

1. Passages quoted by Śaṅkaranārāyaṇa.

| Passages quoted | Quoted under |
|---|---|
| *MBh*, i. 8 | *LBh*, i. 15-16. |
| *MBh*, iii. 1(ii) | *LBh*, iii. 1-3. |
| *MBh*, iii. 33 (ii) | *LBh*, vi. 23-25. |
| *MBh*, iii. 63-65 | *LBh*, viii. 4. |
| *MBh*, iv. 33 | *LBh*, ii. 27. |
| *MBh*, iv. 55 | *LBh*, ii. 7. |
| *MBh*, v. 14 | *LBh*, v. 4. |
| *MBh*, vi. 44 | *LBh*, vii. 1-2. |

2. Passages quoted by Udayadivākara.

| Passages quoted | Quoted under |
|---|---|
| *MBh*, ii. 2(ii) | *LBh*, i. 23 |
| *MBh*, ii. 4(i) | *LBh*, i. 27 |
| *MBh*, iii. 25 | *LBh*, iii. 7-10 |
| *MBh*, iii. 26 | *LBh*, iii. 7-10 |
| *MBh*, iv. 4(ii) | *LBh*, i. 24 |
| *MBh*, iv. 18 | *LBh*, ii. 41 |
| *MBh*, v. 12(i) | *LBh*, v. 15 |
| *MBh*, v. 33 | *LBh*, v. 15 |
| *MBh*, v. 43(ii) | *LBh*, iv. 17 |
| *MBh*, v. 77 | *LBh*, iv. 21 |
| *MBh*, vi. 56-58 | *LBh*, vii. 12 |
| *MBh*, vii. 20(i) | *LBh*, iv. 2 |

3. Passages quoted by Sūryadeva.

| Passages quoted | Quoted under |
|---|---|
| *MBh*, i. 4-6 | *Ā*, iii. 6 |
| *MBh*, i. 41 | *Ā*, ii. 33 |
| *MBh*, v. 33-35 | *LMā*, iv. 14 |
| *MBh*, vi. 48, 52, and 53 | *LMā*, iv. 6-7 |
| *MBh*, v. 75-76 | *LMā*, iv. 14 |
| *MBh*, vii. 23(iv). | *LMā*, iv. 3 |

4. Passages quoted by Makkibhaṭṭa.

| Passages quoted | Quoted under |
| --- | --- |
| *MBh*, i. 25(1) | *SiŚe*, i. 40-41(i) |
| *MBh*, i. 40(ii) | *SiŚe*, i. 3 |
| *MBh*, iv. 23(ii) | *SiŚe*, ii. 49 |

5. Passages quoted by Parameśvara.

| Passages quoted | Quoted under |
| --- | --- |
| *MBh*, iii. 1(ii) | *LBh*, iii. 3 |
| *MBh*, v. 14 | *LBh*, v. 11-12 |
| *MBh*, v. 15-16(i) | *LBh*, v. 11-12 |
| *MBh*, vi. 45 | *LBh*, vii. 1-2(i) |

6. Passages quoted by Nīlakaṇṭha.

| Passages quoted | Quoted under |
| --- | --- |
| *MBh*, i. 41 | *Ā*, ii. 32-33 |
| *MBh*, i. 42 (ii)-43(i) | ,, |
| *MBh*, i. 45, 46, 47 | ,, |
| *MBh*, i. 50 | ,, |
| *MBh*, i. 51(i) | ,, |
| *MBh*, iv. 2-6 | *Ā*, iii. 22-25 |

| Passages quoted | Quoted under |
|---|---|
| *MBh*, iv. 35 | *Ā*, iii. 3 |
| *MBh*, v. 6 | *Ā*, iii. 22-25 |
| *MBh*, vii. 1(i) | *Ā*, ii. 32-33 |
| *MBh*, vii. 19, 20 | *Ā*, iii. 12-15 |
| *MBh*, vii. 35 | ,, |

7. Passages quoted in the Daśādhyāyī.[1]
   Passage quoted : *MBh*, iii. 9.
   Quoted under : *BJ*, i. 19.

8. Passage quoted by Viṣṇu Śarmā.
   Passage quoted : *MBh*, vii, 20 (ii).
   Quoted under : *ViMā*, i. 19.

[1] *Vide* Sudhākara Dvivedī, *Gaṇaka-taraṅgiṇī*, p. 14.

# GLOSSARY

## of Terms used in the Mahā-Bhāskarīya

*Aṁśa* (अंश) (1) Part, fraction. (2) Degree (°).

*Aṁśaka* (अंशक) Degree.

*Aṁśumat* (अंशुमत्) Sun.

*Akṣa* (अक्ष) (1) Latitude. (2) Five.

*Akṣakarṇa* (अक्षकर्ण) The hypotenuse of the equinoctial midday shadow (of the gnomon).

*Akṣakoṭi* (अक्षकोटि) Colatitude. Also, sometimes, the Rsine of colatitude.

*Akṣaguṇa* (अक्षगुण) The Rsine of latitude.

*Akṣacāpa* (अक्षचाप) The arc of latitude, or simply latitude.

*Akṣacāpaguṇa* (अक्षचापगुण) The Rsine of latitude.

*Akṣajīvā* (अक्षजीवा) The Rsine of latitude.

*Akṣajyā* (अक्षज्या) The Rsine of latitude.

*Akṣabhāga* (अक्षभाग) The degrees of latitude.

*Akṣavalana* (अक्षवलन) See *Valana*.

*Akṣasya valanaṁ* (अक्षस्य वलनम्) *Akṣavalana*. See *Valana*.

*Akṣāṁśa* (अक्षांश) The latitude of a place, terrestrial latitude, or simply latitude.

*Akṣāṁśaka* (अक्षांशक) Same as *Akṣāṁśa*.

*Akṣonnati* (अक्षोन्नति) Inclination of the (Earth's) axis, i.e., the latitude of the place.

*Agata* (अगत) Untraversed portion ; portion to be traversed.

*Agni* (अग्नि) Three.

*Agra* (अग्र) (1) End. (2) Residue, remainder (3) *Agrā*.

*Agraguṇa* (अग्रगुण) The Rsine of *Agrā*.

*Agrā* (अग्रा) The arc of the celestial horizon lying between the east point and the point where a heavenly body rises, or between the west point and the point where a heavenly body sets.

*Aṅga* (अंग) Six.

*Aṅgāraka* (अंगारक) Mars.

*Aṅgula* (अंगुल) Finger-breadth. A unit of linear measure-

ment defined by the breadth of eight barley corns.

*Acala* (अचल) (1) Seven. (2) Fixed. To make *acala* in astronomy means to apply the method of successive approximations.

*Aja* (अज) The sign Aries.

*Ativakra* (अतिवक्र) A planet is said to be *ativakra* when it is in the middle of its retrograde motion.

*Adri* (अद्रि) Seven.

*Adhika-māsa* (अधिकमास) Intercalary month. The Intercalary months denote the excess of the lunar (synodic) months over the solar months in a certain period. Thus intercalary months in a *yuga*=lunar months in a *yuga*—solar months in a *yuga*.

A true intercalary month is one in which the Sun does not pass from one sign into the next.

*Adhikābda* (अधिकाब्द) Intercalary year, i.e., a collection of twelve intercalary months. See *Adhikamāsa*.

*Adhikāha* (अधिकाह) Intercalary day, i.e., intercalary *tithi*.

*Adhimāsa* (अधिमास) Intercalary month. See *Adhikamāsa*.

*Adhimāsaka* (अधिमासक) Same as *Adhimāsa*.

*Adhimāsaśeṣa* (अधिमासशेष) The residue of the intercalary months.

*Adhva* (अध्व) The distance of a place from the prime meridian.

*Adhvā* (अध्वा) Same as *Adhva*.

*Adhvāna* (अध्वान) Same as *Adhva*.

*Anudiś* (अनुदिश्) Parallel.

*Anupāta* (अनुपात) Proportion.

*Anuloma* (अनुलोम) Direct. A planet is said to be *anuloma* when its motion is direct, i.e., from west to east.

*Antyaguṇa* (अन्त्यगुण) See *Antyajīvā*.

*Antyajīvā* (अन्त्यजीवा) The current Rsine-difference, i.e., the Rsine-difference corresponding to the elementary arc occupied by a planet. In Hindu trigonometry a quadrant of a circle is divided into 24 equal parts, called elementary arcs.

*Antyajyā* (अन्त्यज्या) Same as *Antyajīvā*.

*Antyaphala* (अन्त्यफल) Maximum correction due to *mandocca* or maximum correction due to *śighrocca*. The former is equal to the radius of the *manda* epicycle and the latter is equal to the radius of the *śighra* epicycle.

*Apakrama* (अपक्रम) Declination.

*Apakramaguṇa* (अपक्रमगुण) The Rsine of declination.

*Apakramajyā* (अपक्रमज्या) The Rsine of declination.

*Apakramadhanu* (अपक्रमधनु) The arc of declination, or simply declination.

*Apagama* (अपगम) Declination.

*Apacaya* (अपचय) Decrease.

*Apama* (अपम) Declination.

*Apamadhanu* (अपमधनु) The arc of declination, i.e., declination.

*Apamo guṇaḥ* (अपमो गुणः) The Rsine of declination.

*Apavarta* (अपवर्त) The greatest common divisor; abrader.

*Abdapa* (अब्दप) The lord of the year, i.e., the planet which is the regent of the first day of the year.

*Abdhi* (अब्धि) Four.

*Abhyāsa* (अभ्यास) Multiplication.

*Abhra* (अभ्र) Zero.

*Amṛtatejas* (अमृततेजस्) Moon.

*Amṛdadīdhiti* (अमृतदीधिति) Moon.

*Ambara* (अम्बर) Zero.

*Ambaroruparidhi* (अम्बरोरुपरिधि) The word *ambara* means, according to Hindu astronomers, "that part of the sky which is illuminated by the rays of the Sun." [1]The word *ambaroruparidhi* likewise means "the periphery of the illuminated sphere of the sky".

*Ayana* (अयन) The northward or southward course of a planet, particularly the Sun. The *ayana* of a planet is north or south according as the planet lies in the half-orbit beginning with the *sāyana* sign Capricorn or in that beginning with the *sāyana* sign Cancer.

*Ayuta* (अयुत) Ten thousand.

*Arka* (अर्क) (1) Sun. (2) Twelve.

*Arkaputra* (अर्कपुत्र) Saturn.

*Arkavarṣa* (अर्कवर्ष) Solar year.

*Arkasambhava*(*māsa*) (अर्कसम्भव मास) Solar month.

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[1] यावन्तमाकाशप्रदेशं रवेर्मयूखाः अभिद्योतयन्ति तावानिह प्रदेशोऽम्बरशब्देनाभिधीयते। (गोविन्दस्वामी)

*Ardhacaturtha* (अर्धचतुर्थ) Three and a half ($3\frac{1}{2}$). Literally, four minus half.

*Ardhapañcaka* (अर्धपञ्चक) or *Ardhapañcama* (अर्धपञ्चम) Four and a half ($4\frac{1}{2}$). Literally, five minus half.

*Ardhavistara* (अर्धविस्तर) Semi-diameter, radius, or 3438′.

*Ardhāstamita* (अर्धास्तमित) Half-set.

*Avanati* (अवनति) (1) Meridian zenith distance. (2) Celestial latitude. (3) Parallax in celestial latitude.

*Avanatilava* (अवनतिलव) The degrees of meridian zenith distance.

*Avanatilavajīvā* (अवनतिलवजीवा) The Rsine of *avanatilava*.

*Avanatiliptikā* (अवनतिलिप्तिका) *Avanati* in minutes of arc.

*Avanāma* (अवनाम) Zenith-distance.

*Avama* (अवम) Omitted lunar days or omitted *tithis*.

*Avamarātraśeṣa* (अवमरात्रशेष) The residue of the omitted lunar days.

*Avamaśeṣa* (अवमशेष) The residue of the omitted lunar days.

*Avalambaka* (अवलम्बक) (1) Plumb. (2) The Rsine of colatitude.

*Avalambakaguṇa* (अवलम्बकगुण) The Rsine of colatitude.

*Avaśeṣa* (अवशेष) Remainder.

*Aviśiṣṭa* (अविशिष्ट) Obtained by applying the method of successive approximations.

*Aviśeṣakarṇa* (अविशेषकर्ण) The distance (lit. hypotenuse) obtained by the method of successive approximations.

*Aviśeṣakarma* (अविशेषकर्म) The method of successive approximations.

*Aviśeṣaṇa* (अविशेषण) To perform *Aviśeṣakarma*.

*Aviśeṣatithi* (अविशेषतिथि) The *tithi* (i.e., the time of apparent conjunction of the sun and Moon) obtained by the method of successive approximations.

*Aviśeṣanāḍī* (अविशेषनाडी) The *nāḍīs* obtained by the method of successive approximations.

*Aviśeṣavidhi* (अविशेषविधि) See *Aviśeṣakarma*.

*Aviślista* (अविश्लिष्ट) Same as *Aviśista.*

*Avisama* (अविषम) Even.

*Aśvi* (अश्वि) Two.

*Aśvin* (अश्विन्) Two.

*Asti* (अष्टि) Sixteen.

*Asakṛt* (असकृत्) Repeatedly, or by using the method of successive approximations.

*Asita* (असित) (1) Dark. (2) The unilluminated part of the Moon's disc. (3) Saturn.

*Asita-pakṣa* (असितपक्ष) The dark half of a lunar month.

*Asu* (असु) A unit of time equivalent to 4 seconds.

*Asṛktanu* (असृक्तनु) Mars. Mars is called *asṛktanu* (*asṛk*= blood, *tanu*=body) because it is red in colour.

*Asta* (अस्त) Setting.

*Astakāla* (अस्तकाल) Time of setting.

*Astalagna* (अस्तलग्न) The setting point of the ecliptic, i.e. that point of the ecliptic which lies on the western horizon.

*Astasūtra* (अस्तसूत्र) The rising-setting line (*udayāstasūtra*).

*Astodayāgrarekhā* (अस्तोदयाग्ररेखा) The rising-setting line.

*Ahargaṇa* (अहर्गण) The number of days elapsed since the beginning of Kaliyuga (or any other epoch).

*Aharmāna* (अहर्मान) The length of day.

*Ahorātra* (अहोरात्र) A day and night, a nychthemeron.

*Ahorātra-viṣkambha* (अहोरात्रविष्कम्भ) Day-radius.

*Ahnāṁ gaṇaḥ* (अह्नां गणः) Same as *Ahargaṇa.*

*Ahnāṁ nicayaḥ* (अह्नां निचयः) Same as *Ahargaṇa.*

*Ākāśa* (आकाश) Zero.

*Āpya* (आप्य) *Pūrvāṣāḍha,* the twentieth *nakṣatra.*

*Āyāma* (आयाम) Length.

*Āra* (आर) Mars.

*Ārki* (आर्कि) Saturn.

*Āśā* (आशा) (1) Direction. (2) Ten.

*Āsanna* (आसन्न) Approximate.

*Āstamika* (आस्तमिक) Pertaining to sunset.

*Āsphujit* (आस्फुजित्) Venus.

*Āhnika* (आह्निक) (1) Pertaining to day. (2) A special astronomical term used by Bhāskara I. See *MBh,* i. 16-18.

*Ina* (इन) (1) Sun. (2) Twelve.

*Indu* (इन्दु) (1) Moon. (2) One.

*Indūcca* (इन्दूच्च) Moon's apogee, i.e., the remotest point of the Moon's orbit.

*Indriya* (इन्द्रिय) Five.

*Indvahaḥ* (इन्द्वहः) Lunar day or *tithi*.

*Iṣu* (इषु) Five.

*Iṣṭa* (इष्ट) Given, or desired, or chosen at pleasure.

*Ucca* (उच्च) The *ucca* is the apex of a planet's orbit. It is of two kinds: (1) *mandocca*, i.e., the apex of slow motion, and (2) *śīghrocca*, i.e., the apex of fast motion. In Hindu astronomy, the *mandocca* is defined to be the remotest point of the planet's orbit where the planet appears smallest[1]. It is therefore the same as the "apogee" of modern astronomy. The *śīghrocca* of the superior planets is an imaginary body which remains in the same direction as the mean Sun; that of an inferior planet lies approximately in the same direction from the Earth as the actual planet is from the Sun.

*Uccabhukti* (उच्चभुक्ति) (Daily) motion of the *ucca*; apsidal motion.

*Utkrama* (उत्क्रम) Reverse order.

*Utkramaguṇa* (उत्क्रमगुण)) Same as *Utkramajyā*.

*Utkramajīvā* (उत्क्रमजीवा) Same as *Utkramajyā*.

*Utkramajyā* (उत्क्रमज्या) Rversed-sine (= Radius × versed-sine).

*Uttara* (उत्तर) North.

*Uttargola* (उत्तरगोल) Northern hemisphere, i.e. the hemisphere lying to the north of of the equator.

*Udak* (उदक्) North.

*Udayajyā* (उदयज्या) The *agrā* of the rising point of a planet's orbit.

*Udayaprāṇa* (उदयप्राण) Times of rising of the signs measured in *asus*.

*Udayarāśiprāṇapiṇḍa* (उदयराशिप्राणपिंड) The time in *asus* of rising of the rising sign.

*Udayalagna* (उदयलग्न) The rising point of the ecliptic, i.e., the horizon-ecliptic point in the east.

[1] यत्र ग्रहाः सूक्ष्मा लक्ष्यन्ते कर्णस्य महत्वात् स आकाशप्रदेश उच्चसंज्ञितः । See Bhāskara I's comm. on *Ā*, iii 4(i).

*Udayāsu* (उदयासु) Times of rising (of the signs) in *asus*.

*Udyāstamaya* (उदयास्तमय) Rising and setting.

*Unnati* (उन्नति) Elevation.

*Uparāga* (उपराग) Eclipse.

*Uṣṇatejas* (उष्णतेजस्) Sun.

*Uṣṇadīdhiti* (उष्णदीधिति) Sun.

*Ṛtu* (ऋतु) Six.

*Aindrāgna* (ऐन्द्राग्न) The name of the sixteenth *nakṣatra* Viśākhā.

*Aindrī* (ऐन्द्री) East.

*Oja* (ओज) Odd.

*Kakubh* (ककुभ्) Ten.

*Kakṣyā*(कक्ष्या) Orbit of a planet.

*Kanyakā*(कन्यका) The sign Virgo.

*Kapāla* (कपाल) Hemisphere.

*Karaṇa* (करण) (1)Process; working. (2) The name of one of the principal elements of the Hindu Calendar.

*Karkaṭa*(कर्कट)(1)A pair of compasses. (2) The sign Cancer.

*Karṇa* (कर्ण)(1) The hypotenuse of a right-angled triangle. (2)The distance of a planet.

*Karṇasūtra* (कर्णसूत्र) Hypotenuse-line.

*Kalā* (कला) Minute of arc.

*Kalākarṇa* (कलाकर्ण) The true distance of a planet in minutes of arc.

*Kalānāṁ śeṣaḥ* (कलानां शेष:) The residue of the minutes (*kalāśeṣa*).

*Kaliyuga* (कलियुग) According to Bhāskara I, Kaliyuga is a period of 1080000 solar years. The current Kaliyuga began on Friday, February 18, B. C. 3102, at sunrise at Laṅka.

*Kārmuka* (कार्मुक) Arc.

*Kālabhāga* (कालभाग) Degrees of time. A degree of time is equivalent to 60 *asus* or 10 *vināḍīs*.

*Kāṣṭha* (काष्ठ) (1) Arc. (2) Direction.

*Kāṣṭhā* (काष्ठा) Direction.

*Kīlaka* (कीलक) Gnomon.

*Kīlakāgraguṇa*(कीलकाग्रगुण) Same as *Śaṅkvagra*.

*Kuja* (कुज) Mars.

*Kujāśā* (कुजाशा) South.

*Kuṭila* (कुटिल) Retrograde.

*Kuṭṭa* (कुट्ट) Pulveriser. See *Kuṭṭākāra*.

*Kuṭṭana* (कुट्टन) The Process of solving a pulveriser (*Kuṭṭākāra*).

*Kuṭṭākāra* (कुट्टाकार) Pulveriser. Equations of the type

$N = ax + r = by + s$ (1)
or $ax - c = by$ (2)
are called in Hindu mathematics by the name *kuṭṭākāra*. A *kuṭṭākāra* (pulveriser) is called *sāgra* (residual) or *niragra* (non-residual) according as it is of the type (1) or (2).

*Kumbha* (कुम्भ) The sign Aquarius.

*Kulīra* (कुलीर) The sign Cancer.

*Kṛta* (कृत) Four.

*Kṛti* (कृति) Square.

*Kṛttikā* (कृत्तिका) The name of the third *nakṣatra*.

*Kendra* (केन्द्र) (1) Anomaly. The *kendra* is of two kinds: *manda-kendra* and *śighra-kendra*. *The manda-kendra* of a planet is equal to "the longitude of the planet minus the longitude of the planet's *mandocca* (apogee)," and the *śighra-kendra* of a planet is equal to the "longitude of the planet's *śighrocca* minus the longitude of the planet." (2) Centre.

*Kendrajyā* (केन्द्रज्या) The Rsine of *kendra*.

*Koṭi* (कोटि) See *Bāhu*.

*Koṭikā* (कोटिका) Same as *Koṭi*.

*Koṭiphala* (कोटिफल) The result obtained by multiplying the Rsine of *koṭi* due to a planet's *kendra* by the epicycle and dividing the resultting product by 360.

*Koṭisādhana* (कोटिसाधन) Same as *Koṭiphala*.

*Krama* (क्रम) (1) Serial order. (2) Odd quadrant.

*Kramaguṇa* (क्रमगुण) Same as *Kramajyā*.

*Kramajyā* (क्रमज्या) Rsine ( = Radius × sine).

*Krānti* (क्रान्ति) Declination.

*Kriya* (क्रिय) The sign Aries.

*Kṣamādina* (क्षमादिन) Civil day.

*Kṣitiguṇa* (क्षितिगुण) Same as *Kṣitijyā*.

*Kṣitijaguṇa* (क्षितिजगुण) Same as *Kṣitiguṇa*.

*Kṣitijā* (क्षितिजा) A corrupt form of *Kṣitijyā*.

*Kṣitijīvā* (क्षितिजीवा) Same as *Kṣitijyā*.

*Kṣitijyā* (क्षितिज्या) Earthsine. The distance between the rising-setting line and the line joining the points of intersection of the diurnal circle and the six o'clock circle.

*Kṣitidhara* (क्षितिधर) Seven.

*Kṣitiputra* (क्षितिपुत्र) Mars.

*Kṣitimaurvī* (क्षितिमौर्वी) Same as *Kṣitijyā*.

*Kṣipti* (क्षिप्ति) Celestial latitude.

*Kṣetranirmāṇa* (क्षेत्रनिर्माण) Celestial longitude.

*Kṣepa* (क्षेप) Quantity to be added.

*Kṣoṇīdhara* (क्षोणीधर) Seven.

*Kha* (ख) Zero.

*Khamadhya* (खमध्य) Meridian.

*Khecara* (खेचर) Planet.

*Gagana* (गगन) (1) Meridian. (2) Zero.

*Gaganasya vṛttaṁ* (गगनस्य वृत्तं) The circumference of the sky. See *Ambaroruparidhi*.

*Gaṇa* (गण) Used in the sense of *Bhagaṇa*.

*Gata* (गत) Traversed, elapsed.

*Gati* (गति) Motion. Generally used in the sense of "daily motion".

*Gantavya* (गन्तव्य) To be traversed.

*Guṇa* (गुण) (1) Multiple or multiplication.(2) Rsine. (3)Three.

*Guṇakāra* (गुणकार) Multiplier, coefficient.

*Guṇapratāna* (गुणप्रतान) Rsine.

*Guṇaphala* (गुणफल) *Bāhuphala* and *koṭiphala*.

*Guru* (गुरु) Jupiter.

*Gṛha* (गृह) Sign.

*Go* (गो) The sign Taurus.

*Gola* (गोल) Hemisphere.

*Golakhaṇḍa* (गोलखण्ड) The semi-diameter of the (celestial) sphere. (गोल=sphere, खण्ड =half)

*Golabheda* (गोलभेद) Same as *Golakhaṇḍa*. (भेद=खण्ड=half)

*Graha* (ग्रह) (1) Planet. (2) Eclipse.

*Grahagaṇita* (ग्रहगणित) Astronomy.

*Grahacāra* (ग्रहचार) Motion of a planet.

*Grahaṇa* (ग्रहण) Eclipse.

*Grahatanu* (ग्रहतनु) A special term used by Bhāskara I. See *MBh*, i. 29.

*Grahadeha* (ग्रहदेह) Same as *Grahatanu*.

*Grahayoga* (ग्रहयोग) Conjunction of planets.

*Grahāṇāṁ tanuḥ* (ग्रहाणां तनुः) *Grahatanu*.

*Grahoparāga* (ग्रहोपराग) Eclipse.

*Grāsa* (ग्रास) (1) Eclipse. (2) Measure of an eclipse. (2) Beginning of an eclipse.

*Grāsamadhya* (ग्रासमध्य) The middle of an eclipse.

*Grāsaśalākā* (ग्रासशलाका) A needle (or line) of length equal to the portion of the diameter eclipsed.

*Grāsādi* (ग्रासादि) The beginning of an eclipse.

*Grāhaka* (ग्राहक) The eclipsing body, the eclipser.

*Grāhya* (ग्राह्य) The eclipsed body.

*Ghaṭikā* (घटिका) Same as *Ghaṭī*.

*Ghaṭī* (घटी) A unit of time equivalent to 24 minutes.

*Ghana* (घन) Cube.

*Ghāta* (घात) Product, multiplication.

*Cakra* (चक्र) Circle, twelve signs, or 360°.

*Caturasra* (चतुरस्र) Quadrilateral.

*Candra* (चन्द्र) (1) Moon. (2) One.

*Candraka* (चन्द्रक) Same as *Candra*.

*Cara* (चर) Ascensional difference. It is defined by the arc of the celestial equator lying between the six-o'clock circle and the hour circle of a heavenly body at rising.

*Caradala* (चरदल) Ascensional difference. See *Cara*.

*Cala* (चल) *Śīghrocca*.

*Calocca* (चलोच्च) *Śīghrocca*.

*Cāpa* (चाप) (1) The sign Sagittarius. (2) Arc.

*Cāra* (चार) Motion or daily motion.

*Citrā* (चित्रा) The name of the fourteenth *nakṣatra*.

*Caitra* (चैत्र) The name of the first month of the year.

*Chāyā* (छाया) (1) Shadow. (2) The Rsine of the zenith distance.

*Chāyādairghya* (छायादैर्घ्य) Same as *Bhūcchāyādairghya*.

*Chāyābhramaṇa* (छायाभ्रमण) The path of the end of the shadow (of the gnomon).

*Chidra* (छिद्र) Nine.

*Cheda* (छेद) Divisor or denominator.

*Chedyaka* (छेद्यक) Projection, or graphical representation.

*Jaladhara* (जलधर) Four.

*Jaladhi* (जलधि) Four.

*Jalapadik* (जलपदिक्) West.

*Jaleśadik* (जलेशदिक्) West.

*Jina* (जिन) Twenty-four.

*Jīva* (जीव) Jupiter.

*Jīvadina* (जीवदिन) Thursday.

*Jīvā* (जीवा) (1)Rsine (= Radius × sine). (2) The Rsine-differences corresponding to the twenty-four divisions of the quadrant.

*Jīvābhukti* (जीवाभुक्ति) True daily motion derived with the help of the table of Rsine-differences.

*Jūka* (जूक) The sign Libra.

*Jña* (ज्ञ) The planet Mercury.

*Jyā* (ज्या) Same as *Jīvā*.

*Jyāsaṅkalita* (ज्यासंकलित) Used in the sense of "the given *Jyā*".

*Jyau* (ज्यौ) Jupiter.

*Tatparā* (तत्परा) Third of arc, *i.e.*, one-sixtieth of a second of arc.

*Tattva* (तत्त्व) Twenty-five.

*Tantra* (तन्त्र) Principle, doctrine, theory, rule, method. Also, a class of astronomical works.

*Tama* (तम) (1) The shadow of the Earth), particularly, the section of the shadow cone where the Moon crosses it, by a plane perpendicular to the axis of the shadow cone. (2) The Moon's ascending node.

*Tamomaya* (तमोमय) The Moon's ascending node.

*Tārakā* (तारका) Star.

*Tārā* (तारा) Star.

*Tārāgraha* (ताराग्रह) The star-planets. The planets Mars, Mercury, Jupiter, Venus, and Saturn are called star-planets (*tārāgraha*) in Hindu astronomy.

*Tigmāṁśu* (तिग्मांशु) (1) The Sun. (2) Twelve.

*Tithi* (तिथि) (1) Lunar day (called *tithi*). (2) Time of conjunction or opposition of the Sun and Moon. (3) Time of beginning, middle, or end of eclipse. (4) Fifteen. (5) Thirty.

*Tithipraṇāśa* (तिथिप्रणाश) Omitted *tithis*.

*Tithyanta* (तिथ्यन्त) Time of conjunction or opposition of the Sun and Moon.

*Tiryak* (तिर्यक्) (1) Oblique. (2) Transverse.

*Tuṅga* (तुंग) Same as *Ucca*.

*Turīya* (तुरीय) One-fourth.

*Tulā* (तुला) The sign Libra.

*Tulādhara* (तुलाधर) The sign Libra.

*Trigṛhaguṇa* (त्रिगृहगुण) The Rsine of three signs, i.e.,

the radius or 3438′.

*Trijyā* (त्रिज्या) Radius or 3438′.

*Tribhavana* (त्रिभवन) Three signs.

*Trimaurvī* (त्रिमौर्वी) Radius.

*Trairāśika* (त्रैराशिक) Rule of Three.

*Dala* (दल) Half.

*Daśaguṇa* (दशगुण) The ten Rsines, viz. Sun's *udayajyā*, Sun's *madhyajyā*, Sun's *dṛkkṣepajyā*, Sun's *dṛgjyā*, Sun's *dṛggatijyā*, Moon's *udayajyā*, Moon's *madhyajyā*, Moon's *dṛkkṣepajyā*, Moon's *dṛgjyā*, and Moon's *dṛggatijyā*.

*Daśajīvā* (दशजीवा) Same as *Daśaguṇa*.

*Dasra* (दस्र) Two.

*Dahana* (दहन) Three.

*Dik* (दिक्) (1) Direction. (2) Ten.

*Dikka* (दिक्क) Direction.

*Ditisūnupūjita* (दितिसूनुपूजित) Venus.

*Dina* (दिन) (1) Day. (2) Fifteen.

*Dinagaṇa* (दिनगण) Same as *Ahargaṇa*

*Dinamāna* (दिनमान) Measure (or length) of the day.

*Dinarāśi* (दिनराशि) *Ahargaṇa*.

*Dinānāṁ gaṇaḥ* (दिनानां गण:) Same as *Ahargaṇa*.

*Divasa* (दिवस) (1) Day. (2) *Ahargaṇa*.

*Divasaguṇārdha* (दिवसगुणार्ध) The day radius.

*Divasajīvā* (दिवसजीवा) The day radius.

*Divasayojana* (दिवसयोजन) The number of *yojanas* that a planet traverses in a day.

*Divasavistarabheda* (दिवसविस्तरभेद) The day radius.

*Divāguṇa* (दिवागुण) The day radius.

*Divicara* (दिविचर) (1) Seven. (2) Planet.

*Diś*. (दिश्) (1) Direction. (2) Ten.

*Dṛkkṣepa* (दृक्क्षेप) The *dṛkkṣepa* is the shortest arcual distance of the planet's orbit from the zenith. It is also used for the Rsine of that distance.

*Dṛggati* (दृग्गति) Arc corresponding to the *Dṛggatijyā*.

*Dṛggatijyā* (दृग्गतिज्या) The *dṛggatijyā* is the distance from the zenith of the plane of a planet's circle of celestial longitude, or the Rsine of the shortest distance from

the zenith of a planet's circle of celestial longitude.

*Drgguṇa* (दृग्गुण) The Rsine of zenith distance.

*Drgjīvā* (दृग्जीवा) The Rsine of zenith distance.

*Drgjyā* (दृग्ज्या) The Rsine of zenith distance.

*Dṛḍha* (दृढ़) Prime.

*Dṛśya-candra* (दृश्यचन्द्र) The longitude of the Moon corrected for the visibility corrections.

*Devapūjya* (देवपूज्य) Jupiter.

*Devamantri* (देवमन्त्रि) Jupiter.

*Deśakāla* (देशकाल) Used in the sense of *deśāntara-kāla*, i.e., the longitude-correction in terms of time.

*Deśajāta-kāla* (देशजातकाल) See *Deśakāla*.

*Deśāntara* (देशान्तर) The longitude of the place. That is, either the distance of the local place from the prime meridian, or the difference between the local and standard times.

*Deśāntara-karma* (देशान्तर-कर्म) Correction for the longitude of the place, the longitude-correction.

*Deśāntara-ghaṭī* (देशान्तर-घटी) *Deśāntara* in *ghaṭīs*.

*Deha* (देह) Used in the sense of *grahadeha*. See *Grahadeha*.

*Dyugaṇa* (द्युगण) *Ahargaṇa*.

*Dyujyā* (द्युज्या) The day radius.

*Dyuti* (द्युति) Shadow (meaning "the shadow of the gnomon").

*Dyuti-karṇa* (द्युतिकर्ण) The hypotenuse of the shadow (of the gnomon).

*Dyudala* (द्युदल) The day radius.

*Dyurāśi* (द्युराशि) *Ahargaṇa*.

*Dyuvyāsa* (द्युव्यास) The day radius.

*Dyuvyāsakhaṇḍa* (द्युव्यासखंड) The day radius.

*Dyuvyāsa-bheda* (द्युव्यासभेद) The day radius.

*Dyuvāysārdha* (द्युव्यासार्ध) The day radius.

*Dvyagra* (द्वयग्र) A *sāgra kuṭṭākāra* (residual pulveriser) with two residues.

*Dhana* (धन) Addition.

*Dhaniṣṭhā* (धनिष्ठा) The name of the twenty-third *nakṣatra*.

*Dhanuḥ* (धनुः) (1) Arc. (2) The sign Sagittarius.

*Dhanuḥ-khaṇḍa* (धनुःखण्ड) In Hindu astronomy, the qua-

drant of a circle is divided into twenty-four equal parts and these parts are known as *kāṣṭha*, *dhanu*, *dhanuḥkhaṇḍa*, *dhanurbhāga*, etc.

*Dhanurbhāga* (धनुर्भाग) 225′.

*Dhanuṣ* (धनुष्) (1) Arc. (2) 225′.

*Dhanvin* (धन्विन्) The sign Sagittarius.

*Dharaṇīdina* (धरणीदिन) Civil day.

*Dharādivasa* (धरादिवस) Civil day.

*Dharāsuta* (धरासुत) Mars.

*Dhātrīdhara* (धात्रीधर) Seven.

*Dhṛti* (धृति) Eighteen.

*Dhruvaka* (ध्रुवक) A technical term. See *MBh*, i. 29.

*Nakṣatra* (नक्षत्र)(1)Star. (2)Asterism. (3) Twenty-seven.

*Nakṣatragaṇa* (नक्षत्रगण) Same as *Bhagaṇa*.

*Nakṣatra-bheda* (नक्षत्रभेद) Occultation of stars.

*Nakha* (नख) Twenty.

*Naga* (नग) Seven.

*Natabhāga* (नतभाग) The degrees (*bhāga*) of zenith distance (*nata*).

*Natāṁśa* (नतांश) Zenith distance.

*Nati* (नति) (1) The meridian zenith distance. (2) Celestial latitude as corrected for parallax in latitude. (3) Parallax in latitude.

*Natijyā* (नतिज्या) The Rsine of the meridian zenith distance.

*Nanda* (नन्द) Nine.

*Nabha* (नभ) Zero.

*Nara* (नर) (1) The sign Gemini. (2) Gnomon. (3) The Rsine of altitude.

*Nā* (ना) The Rsine of altitude.

*Nāḍikā* (नाडिका) A unit of time equivalent to 24 minutes.

*Nāḍī* (नाडी) See *Nāḍikā*.

*Nirakṣa* (निरक्ष) Equator.

*Nirakṣāsu* (निरक्षासु) *Asus* of the right ascension, i.e., the time in *asus* of rising at the the equator.

*Nirapavartita* (निरपवर्तित) Unabraded, unabridged.

*Niśākara* (निशाकर) (1) Moon. (2) One.

*Niścalakriyā* (निश्चलक्रिया) Method of successive approximations.

*Niḥśvāsalava* (निःश्वासलव) *Asus*.

*Nṛ* (नृ) Gnomon.

*Netra* (नेत्र) Two.

*Nemi* (नेमि) Circumference, periphery.

*Pakṣa* (पक्ष) (1) Lunar fortnight, period from new moon to full moon, or from full moon to new moon. (2) Two

*Pada* (पद) (1) Quadrant. (2) Square root.

*Parakrānti* (परक्रान्ति) (Sun's) greatest declination, or obliquity of the ecliptic.

*Paramāpama* (परमापम) Same as *Parakrānti.*

*Paridhi* (परिधि) (1) Circumference, periphery. (2) Epicycle.

*Parilekha* (परिलेख) Projection, graphical representation.

*Parvata* (पर्वत) Seven.

*Parvamadhya* (पर्वमध्य) The middle of the eclipse.

*Pala* (पल) Latitude.

*Palajīvā* (पलजीवा) The Rsine of the latitude.

*Palajyā* (पलज्या) The Rsine of the latitude.

*Palabhāga* (पलभाग) The degrees of the latitude.

*Palāṅgula* (पलाङ्गुल) Used in the sense of '*palabhāṅgula*', i. e., the *aṅgulas* of the equinoctial midday shadow.

*Palāṁśa* (पलांश) The degrees of the latitude.

*Paścārdha* (पश्चार्ध) The western half.

*Pāta* (पात) The ascending node of a planet's orbit (on the ecliptic).

*Pātabhāga* (पातभाग) The degrees of the longitude of the ascending node.

*Puṣkara* (पुष्कर) Three.

*Pūrvalagna* (पूर्वलग्न) The horizon-ecliptic point in the east.

*Paṅkti* (पंक्ति) Ten.

*Pratimaṇḍala* (प्रतिमण्डल) Eccentric.

*Pratimaṇḍala-karma* (प्रतिमण्डलकर्म) Processes under the eccentric theory.

*Prabhā* (प्रभा) (1) The shadow of the gnomon. (2) The Rsine of the zenith distance.

*Pralayāstithīnāṁ* (प्रलयास्तिथीनां) Omitted lunar days.

*Prastāra* (प्रस्तार) The statement of possible combinations in a serial order.

*Prāggrāsa* (प्राग्ग्रास) The first contact in an eclipse.

*Prāṇa* (प्राण) Same as *Asu.*

*Prāleyaraśmi* (प्रालेयरश्मि) One.

*Pronnati* (प्रोन्नति) Altitude.

*Phala* (फल) (1) Result. (2) Correction.

*Bava* (बव) The first of the seven movable *karaṇas*. The *karaṇa* is one of the five important elements of the Hindu Calendar.

*Bahula* (बहुल) The *nakṣatra Kṛttikā*.

*Bāhu* (बाहु) (1) The base (of a right-angled triangle). The upright of a right-angled triangle is called *koṭi*. (2) The *bāhu* corresponding to a planet's anomaly. This is the arcual distance of the planet from its apogee or perigee whichever is nearer. Suppose that $\theta$ is the anomaly of a planet (or any arc, whatever). If $\theta$ is less than $\pi/2$, $\theta$ itself is the *bāhu*; if $\theta$ is greater than $\pi/2$ but less than $\pi$, $(\pi-\theta)$ is the *bāhu*; if $\theta$ is greater then $\pi$ but less than $3\pi/2$, $(\theta-\pi)$ is the *bāhu*; and if $\theta$ is greater than $3\pi/2$, $(2\pi-\theta)$ is the *bāhu*. The complement of the *bāhu* is called *koṭi*.

*Bāhuka* (बाहुक) Same as *Bāhu*.

*Bāhujyā* (बाहुज्या) The Rsine of the *bāhu* (of a planet's anomaly).

*Bāhuphala* (बाहुफल) See notes on *MBh*, iv. 6.

*Bāhoḥ phalaṁ* (बाहोः फलं) Same as *Bāhuphala*.

*Bimba* (बिम्ब) The disc of a planet.

*Bimbārdha* (बिम्बार्ध) The semi-diameter of the disc.

*Budhāśā* (बुधाशा) North.

*Bhaṁ* (भं) Twenty-seven.

*Bhaga* (भग) The *nakṣatra* Purvā-phālgunī, the regent of which is Bhaga.

*Bhagaṇa* (भगण) (1) The revolution-number of a planet, *i.e.*, the number of revolutions that a planet performs in a certain period. The revolutions given by *Bhāskara* I correspond to a *yuga*, *i.e.*, to a period of 43,20,000 years. (2) The *nakṣatras*. (3) Twelve signs (or 360°).

*Bhava* (भव) Eleven.

*Bhavana* (भवन) Sign.

*Bhāga* (भाग) (1) Part, fraction. (2) Division. (3) Degree.

*Bhāgalabdha* (भागलब्ध) Quotient.

*Bhāgaśeṣa* (भागशेष) The residue of the degrees.

*Bhāgahāra* (भागहार) Divisor.

*Bhāgahāraka* (भागहारक) Same as *Bhāgahāra*.

*Bhājya* (भाज्य) Dividend

*Bhārgava* (भार्गव) Venus.

*Bhidaḥ* (भिदः) Half.

*Bhukti* (भुक्ति) Motion, or daily motion.

*Bhuja* (भुज) Same as *Bāhu*.

*Bhujā* (भुजा) Same as *Bhuja*.

*Bhujāntara* (भुजान्तर) Correction for the equation of time due to the eccentricity of the ecliptic.

*Bhujāphala* (भुजाफल) The equation of the centre.

*Bhūcchāyā* (भूच्छाया) The Earth's shadow.

*Bhūcchāyādairghya* (भूच्छायादैर्घ्य) The length of the Earth's shadow, *i.e.*, the distance of the vertex of the shadow cone from the Earth's centre.

*Bhūjyā* (भूज्या) See *Kṣitijyā*.

*Bhūta* (भूत) Five.

*Bhūdina* (भूदिन) Civil day.

*Bhūdivasa* (भूदिवस) Civil day.

*Bhūdhara* (भूधर) Seven.

*Bhūbhṛt* (भूभृत्) Seven.

*Bhūmidina* (भूमिदिन) Civil day.

*Bhṛgu* (भृगु) Venus.

*Bhṛguja* (भृगुज) Venus.

*Bheda* (भेद) (1) Half. (2) Occultation of a heavenly body.

*Bhoga* (भोग) Motion.

*Bhauma* (भौम) Mars.

*Maghavadguru* (मघवद्गुरु) Jupiter.

*Maghā* (मघा) Name of the tenth *nakṣatra*.

*Maṇḍala* (मण्डल) Circle; a collection of 12 signs.

*Maṇḍalamadhya* (मण्डलमध्य) The centre of a circle.

*Mati* (मति) An optional number.

*Matsya* (मत्स्य) Fish-figure.

*Madhu* (मधु) Caitra, the first month of the year.

*Madhyakrānti* (मध्यक्रान्ति) The declination of the meridian-ecliptic point.

*Madhyacchāyā* (मध्यच्छाया) The midday shadow (of the gnomon).

*Madhyajātaḥ lambakaḥ* (मध्यजातः लम्बकः) The upright due to the meridian-ecliptic point,

*i.e.*, the Rsine of the altitude of the meridian ecliptic point.

*Madhyajyā* (मध्यज्या) The Rsine of the zenith-distance of the meridian-ecliptic point; the meridian-sine.

*Madhyapariniṣṭhitalambaka* (मध्यपरिनिष्ठितलम्बक) Same as *Madhyajātaḥ lambakaḥ*.

*Madhyalagna* (मध्यलग्न) Meridian-ecliptic point.

*Madhyasūryāvanāma* (मध्यसूर्यविनाम) The zenith distance of the midday Sun, or the meridian zenith distance of the Sun.

*Madhyāvanati* (मध्यावनति) The zenith distance of the midday Sun.

*Mandakendra* (मन्दकेन्द्र) *Manda* anomaly (=longitude of the planet minus longitude of the planet's apogee).

*Mandapāta* (मन्दपात) See *MBh*, vii. 30.

*Mandaphala* (मन्दफल) Correction due to the planet's *mandocca*. In the case of the Sun and Moon, the equation of the centre.

*Mandamaurvīphalacāpa* (मन्दमौर्वीफलचाप) Same as *Mandaphala*.

*Mandavṛtta* (मन्दवृत्त) *Manda* epicycle.

*Mandasiddha* (मन्दसिद्ध) Corrected for the *mandaphala*.

*Mandasiddhi* (मन्दसिद्धि) Correction (of a planet) for the *mandaphala*.

*Mandāntyajīvā* (मन्दान्त्यजीवा) The present Rsine-difference corresponding to the *mandakendra i.e.*, the Rsine-difference of the elementary arc in which the planet lies.

*Mandocca* (मन्दोच्च) The apogee of a planet. See *Ucca*.

*Mandoccakarṇa* (मन्दोच्चकर्ण) See *Mandakarṇa*.

*Mandoccakendra* (मन्दोच्चकेन्द्र) See *Mandakendra*.

*Mandoccavṛtta* (मन्दोच्चवृत्त) *Manda* epicycle.

*Mithuna* (मिथुन) The sign Gemini.

*Mīna* (मीन) (1) Fish-figure, (2) the sign Pisces.

*Muni* (मुनि) Seven.

*Mūla* (मूल) Square root.

*Mṛga* (मृग) The sign Capricorn.

*Meṣa* (मेष) The sign Aries.

*Maitra* (मैत्र) The *nakṣatra* Anurādhā, the regent of which is Mitra.

*Mokṣa* (मोक्ष) The separation of the eclipsed body after an eclipse.

*Maurika* (मौरिक) Minute of arc.

*Maurvī* (मौर्वी) Rsine.

*Yantra* Instrument.

*Yama* (यम) (1) Saturn. (2) Name of the second *nakṣatra* Bharaṇī, whose divinity is Yama. (3) Two.

*Yamala* (यमल) Two.

*Yāmya* (याम्य) South.

*Yāmyagola* (याम्यगोल) The southern hemisphere, i.e., the hemisphere lying to the south of the equator.

*Yāmyottara* (याम्योत्तर) South-north.

*Yāmyottarāyata* (याम्योत्तरायत) Directed south-to-north.

*Yugala* (युगल) Two.

*Yugma* (युग्म) Even.

*Yoga* (योग) (1) Addition. (2) Conjunction of two heavenly bodies.

*Yogatārā* (योगतारा) Junction-stars. These are those prominent stars of the twenty-seven *nakṣatras* which were used by the Hindu astronomers for the study of the conjunction of the planets, especially the Moon, with them.

*Yogabhāga* (योगभाग) The degrees of the longitudes of the junction-stars.

*Yojana* (योजन) The *yojana* is a measure of distance. The length of a *yojana* has differed at different places and at different times. The *yojana* of Āryabhaṭa I and Bhāskara I is roughly equivalent to $7\frac{1}{2}$ miles.

*Randhra* (रन्ध्र) Nine.

*Ravi* (रवि) (1) Sun. (2) Twelve.

*Ravija* (रविज) (1) Saturn. (2) A special term used by Bhāskara I. See *MBh*, i. 27.

*Ravijadivasa* A special term used by Bhāskara I. See *MBh*, i. 28.

*Rasa* (रस) Six.

*Rāma* (राम) Three.

*Rāśi* (राशि) (1) Quantity. (2) Sign.

*Rāśijīvā* (राशिजीवा) The Rsine of one sign, i.e., Rsin (30°).

*Rāhu* (राहु) The Moon's ascending node.

*Rudra* (रुद्र) Eleven.

*Rudhira* (रुधिर) Mars.

*Rūpa* (रूप) One.

*Lagna* (लग्न) The horizon-ecliptic point in the east.

*Laghutantra* (लघुतन्त्र) Short or simplified method.

*Laṅkā* (लङ्का) A place in 0 latitude and 0 longitude. Also see *supra*, p. 47.

*Laṅkārāśyudaya* (लङ्काराश्युदय) Times of rising of the signs at Laṅkā, or right ascensions of the signs.

*Laṅkodaya* (लङ्कोदय) Times of rising (of the signs) at Laṅkā, or right ascensions (of the signs).

*Labdha* (लब्ध) Quotient.

*Lamba* (लम्ब) The Rsine of the colatitude (of the place).

*Lambaka* (लम्बक) The Rsine of the colatitude.

*Lambakaguṇa* (लम्बकगुण) Same as *Lambaka*.

*Lambana* (लम्बन) Parallax in longitude; or, in particular, the difference between the parallaxes in longitude of the Sun and Moon.

*Lambanaliptā* (लम्बनलिप्ता) *Lambana* in longitude in terms of minutes of arc.

*Lambanāntara* (लम्बनान्तर) The *lambana*-difference.

*Lambanāntaranāḍikā* (लम्बनान्तरनाडिका) The *nāḍīs* of the *lambana*-difference, or the *lambana*-difference in terms of *nāḍīs*.

*Lava* (लव) (1) Part, portion, fraction. (2) Degree.

*Liptā* (लिप्ता) Minute of arc.

*Liptikā* (लिप्तिका) Same as *Liptā*.

*Liptikā vipūrvā* (लिप्तिका विपूर्वा) *Viliptikā*; second of arc.

*Vakra* (वक्र) Retrograde.

*Vakragati* (वक्रगति) Retrograde motion.

*Vakragamana* (वक्रगमन) Retrograde motion.

*Vakrīgraha* (वक्रीग्रह) A planet in retrograde motion.

*Vacasāṁ patiḥ* (वचसां पतिः) Jupiter.

*Vatsara* (वत्सर) Year.

*Vapu* (वपु) The body (globe or disc) of a planet.

*Varga* (वर्ग) Square.

*Vartamāna* (वर्तमान) Present, current.

*Vartamānaguṇa* (वर्तमानगुण) The present (or current) Rsine-difference, *i.e.*, the Rsine-difference of the elementary arc occupied by a planet.

*Varṣapa* (वर्षप) The lord of the year, *i.e.*, the planet after whose name the first day of the year bears its name.

*Valana* (वलन) Deflection. *Valana* relates to an eclipsed body. It is the angle subtended at the body by the arc joining the north point of the celestial horizon and the north pole of the ecliptic. *Valana* is generally divided into two components, (i) *Akṣavalana* and (ii) *Ayanavalana*. The *Akṣavalana* is the angle subtended at the body by the arc joining the north point of the celestial horizon and the north pole of the equator. The *Ayanavalana* is the angle subtended at the body by the arc joining the north poles of the equator and the ecliptic.

The *Valana* is also defined as follows: The great circle of which the eclipsed body is the pole is called the horizon of the eclipsed body. Suppose that the prime vertical, equator, and the ecliptic intersect the horizon of the eclipsed body at the points A, B and C towards the east of the eclipsed body. Then arc AB is called the *Akṣavalana*, arc BC is called the *Ayanavalana* and arc AC is called *Valana*.

*Valana* is also called *spaṣṭavalana*.

*Vasu* (वसु) Eight.

*Vahni* (वह्नि) Three.

*Vāruṇī* (वारुणी) West.

*Vi* (वि) Celestial latitude. Evidently, *Vi* is an abbreviated form of *vikṣepa*.

*Vikalā* (विकला) Second of arc.

*Vikāṣṭha* (विकाष्ठ) The arc of celestial latitude.

*Vikṣipti* (विक्षिप्ति) Celestial latitude.

*Vikṣepa* (विक्षेप) Celestial latitude.

*Vikṣepajyā* (विक्षेपज्या) The Rsine of celestial latitude.

*Vikṣepāṁśa* (विक्षेपांश) The degrees of celestial latitude.

*Vighaṭikā* (विघटिका) A unit of time, equivalent to 24 seconds.

*Vidiś* (विदिश्) Contrary direction.

*Vināḍikā* (विनाड्का) Same as *Vighaṭikā*.

*Vināḍī* (विनाडी) Same as *Vināḍikā*.

*Viparītaguṇa* (विपरीतगुण) Rversed-sine.

*Vipulacchāyā* (विपुलच्छाया) Great shadow, meaning "the Rsine of the zenith distance".

*Vipulanara* (विपुलनर) Great gnomon, meaning "the Rsine of altitude."

*Vimaṇḍala* (विमण्डल) The orbit of a planet.

*Vimardārdha* (विमर्दार्ध) Half the duration of totality of an eclipse.

*Vimaurika* (विमौरिक) Second of arc.

*Viyat* (वियत्) Zero.

*Vilagna* (विलग्न) The horizon-ecliptic point in the east.

*Viliptā* (विलिप्ता) Second of arc.

*Viliptikā* (विलिप्तिका) Same as *Viliptā*.

*Vivara* (विवर) Difference, intervening space.

*Viśākhā* (विशाखा) Name of the sixteenth *nakṣatra*.

*Viśeṣa* (विशेष) Difference.

*Viśleṣa* (विश्लेष) Difference.

*Viśva* (विश्व) Thirteen.

*Viṣama* (विषम) Odd.

*Viṣaya* (विषय) Five.

*Viṣuvajyā* (विषुवज्या) The Rsine of the latitude (of a place).

*Viṣuvat* (विषुवत्) The equator.

*Viṣuvatkarṇa* (विषुवत्कर्ण) The hypotenuse of the equinoctial midday shadow.

*Viṣuvatprabhā* (विषुवत्प्रभा) The equinoctial midday shadow.

*Viṣuvadudayarāśiprāṇapiṇḍa* (विषुवदुदयराशिप्राणपिंड) Time in *asus* of rising of the signs at the equator, *i.e.*, right ascension of the signs in terms of *asus*.

*Viṣkambha* (विष्कम्भ) Diameter.

*Viṣṇukrama* (विष्णुक्रम) Three.

*Vistara* (विस्तर) Same as *Vistāra*.

*Vistāra* (विस्तार) (1) Diameter. "*Vyāsa*, *viṣkambha*, and *vistāra* are synonyms", says Bhāskara I. (2) Length,

breadth, etc. "*Āyāma*, *vistāra*, and *dairghya* are synonyms," says Bhāskara I.

*Vihaṅgama* (विहंगम) Planet.

*Vihaga* (विहग) Planet.

*Vihāyas* (विहायस्) Zero.

*Vṛtta* (वृत्त) (1) Circle. (2) Epicycle.

*Vṛttasaṅkhyā* (वृत्तसंख्या) The length of the circumference of a circle.

*Vṛnda* (वृन्द) Cube.

*Vṛṣa* (वृष) The sign Taurus.

*Veda* (वेद) Four.

*Velākuṭṭa* (वेलाकुट्ट) Time-pulveriser. See notes on *MBh*, i. 49.

*Vaidhṛta* (वैधृत) An astronomical phenomenon. See *MBh*, iv. 35.

*Vaiṣuvatī chāyā* (वैषुवती छाया). The equinoctial midday shadow.

*Vyatīpāta* (व्यतीपात) An astronomical phenomenon. See *MBh*, iv. 35.

*Vyāsa* (व्यास) Diameter.

*Vyāsakhaṇḍa* (व्यासखण्ड) Radius.

*Vyāsakhaṇḍanicaya* (व्यासखण्डनिचय) same as *Vyāsakhaṇḍa*.

*Vyāsārdha* (व्यासार्ध) Radius or 3438′.

*Vyoma* (व्योम) Zero.

*Śakratāraka* (शक्रतारक) The *nakṣatra* Jyeṣṭhā, whose regent is Indra.

*Śakraguru* (शक्रगुरु) Jupiter.

*Śaṅku* (शंकु) (1) Gnomon. (2) The Rsine of altitude (of a heavenly body).

*Śaṅkvagra* (शङ्क्वग्र) The distance of the projection of a heavenly body on the plane of the celestial horizon from the planet's rising-setting line.

*Śaṅkvagrajīvā* (शङ्क्वग्रजीवा) Same as *Śaṅkvagra*.

*Śatabhiṣak* (शतभिषक्) The *nakṣatra* Śatabhikhā.

*Śapharikā* (शफरिका) A fish-figure.

*Śara* (शर) (1) Rversed-sine. (2) Five.

*Śaśi* (शशि) (1) The Moon. (2) One.

*Śaśija* (शशिज) Lunar.

*Śālin* (शालिन्) One.

*Śikhi* (शिखि) Three.

*Śilīmukha* (शिलीमुख) Five.

*Śiva* (शिव) Eleven.

*Śīghra* (शीघ्र) Same as *Śīghrocca*.

*Śīghrakarṇa* (शीघ्रकर्ण) The distance of a planet obtained by the *śīghrocca* process.

*Śīghrakendra* (शीघ्रकेन्द्र) The *śīghra* anomaly. See *Kendra*.

*Śīghrakendraphala* (शीघ्रकेन्द्रफल) *Śīghraphala*, *i.e.*, correction due to the *śīghrocca*.

*Śīghrajaḥ karṇaḥ* (शीघ्रजः कर्णः) = *Śīghrakarṇa*.

*Śīghranyāyāptacāpa* (शीघ्रन्यायाप्तचाप) = *Śīghraphala*.

*Śīghraparidhi* (शीघ्रपरिधि) *Śīghra* epicycle.

*Śīghrapāta* (शीघ्रपात) See *MBh*, vii. 31.

*Śīghravṛtta* (शीघ्रवृत्त) *Śīghra* epicycle.

*Śīghrasiddha* (शीघ्रसिद्ध) Corrected for the *śīghraphala*.

*Śīghrāntyajīvā* (शीघ्रान्त्यजीवा) The present Rsine-difference relating to the *śīghra* (*kendra*).

*Śīghrocca* (शीघ्रोच्च) See *Ucca*.

*Śīghroccavṛtta* (शीघ्रोच्चवृत्त) *Śīghra* epicycle.

*Śītakiraṇa* (शीतकिरण) (1) Moon. (2) One.

*Śītaraśmi* (शीतरश्मि) (1) Moon. (2) One.

*Śītāṁśu* (शीतांशु) (1) Moon. (2) One.

*Śukla* (शुक्ल) The illuminated part of the Moon's disc; the phase of the Moon.

*Śṛṅgonnati* (शृङ्गोन्नति) The elevation of the Moon's horns.

*Śaila* (शैल) Seven.

*Śodhana* (शोधन) Subtraction.

*Śodhanīya* (शोधनीय) A subtractive quantity technically called *śodhanīya* or *śodhya*. See *MBh*, i. 28.

*Śodhya* (शोध्य) See *Śodhanīya*.

*Śauklya* (शौक्ल्य) The illuminated part of the Moon's disc.

*Śravaṇa* (श्रवण) (1) Name of the 22nd *nakṣatra*. (2) The Hypotenuse (of a right-angled triangle).

*Saṁskṛta* (संस्कृत) Corrected.

*Sakalaguṇa* (सकलगुण) Radius or 3438′.

*Saṅkalita* (संकलित) Sum, total.

*Sannati* (सन्नति) Meridian zenith distance.

*Sama* (सम) Even.

*Samamaṇḍala* (सममण्डल) The prime vertical.

*Samamaṇḍalajā chāyā* (सममण्डलजा छाया) The prime vertical shadow.

*Samamaṇḍalaśaṅku* (सममण्डलशंकु) The Rsine of the prime vertical altitude.

*Samarekhā* (समरेखा) The prime meridian.

*Samalipta* (समलिप्त) Two planets are said to be *samalipta* (समलिप्त) when their longitudes are equal up to minutes.

*Samavalambajyā* (समवलम्बज्या) The Rsine of the colatitude.

*Sarvāpama* (सर्वापम) The greatest declination (of the Sun), i. e., the obliquity of the ecliptic.

*Sāgara* (सागर) Four.

*Sārpamastaka* (सार्पमस्तक) An astronomical phenomenon. See *MBh*, iv. 35.

*Siṁha* (सिंह) The sign Leo.

*Sita* (सित) (1) The illuminated part of the Moons's disc; the phase of the Moon. (2) The light half of the month. (3) Venus.

*Sitakhaga* (सितखग) Venus.

*Sitapakṣa* (सितपक्ष) The light half of a lunar month, light fortnight.

*Sitabindu* (सितबिंदु) That point of the Moon's diameter which lies at the end of the illuminated part of the Moon.

*Sitamāna* (सितमान) The measure of the illuminated part of the Moon's disc.

*Suranāthaguru* (सुरनाथगुरु) Jupiter.

*Surapadik* (सुरपदिक्) East.

*Suredya* (सुरेड्य) Jupiter.

*Sūri* (सूरि) Jupiter.

*Sūrya* (सूर्य) (1) Sun. (2) Twelve.

*Sūryakakṣyā* (सूर्यकक्ष्या) The orbit of the Sun, the ecliptic.

*Sūryaja* (सूर्यज) Saturn.

*Saiṁhikeya* (सैंहिकेय) The ascending node of the Moon's orbit. (*Saiṁhikeya* literally means Rāhu, son of Siṁhikā).

*Somaja* (सोमज) Mercury.

*Somasūnu* (सोमसूनु) Mercury.

*Saumya* (सौम्य) (1) North. (2) The *nakṣatra* Mṛgaśirā. (3) Mercury.

*Sauri* (सौरि) Saturn.

*Sthiti* (स्थिति) Duration (of an eclipse).

*Sthitidala* (स्थितिदल) Half the duration (of an eclipse).

*Sthityardha* (स्थित्यर्ध) Half the duration (of an eclipse).

*Sthūla* (स्थूल) Gross, approximate.

*Sparśa* (स्पर्श) Contact.

*Sparśakāla* (स्पर्शकाल) Time of the first contact (in an eclipse).

*Spaṣṭa* (स्पष्ट) True, corrected.

*Sphuṭa* (स्फुट) True.

*Sphuṭamadhya* (स्फुटमध्य) True-mean; the true-mean planet.

*Sphuṭamadhyama* (स्फुटमध्यम) Same as *sphuṭamadhya.*

*Sphuṭayojana* (स्फुटयोजन) Used in the sense of *sphuṭayojanakarṇa.*

*Sphuṭayojanakarṇa* (स्फुटयोजनकर्ण) The true distance (of a planet) in terms of *yojanas.*

*Sphuṭavṛtta* (स्फुटवृत्त) True or corrected epicycle.

*Svara* (स्वर) Seven.

*Harija* (हरिज) Horizon.

*Hāra* (हार) Divisor.

*Hārarāśi* (हारराशि) Divisor.

*Himāṁśu* (हिमांशु) (1) Moon. (2) One.

*Hīna* (हीन) (1) Less. (2) Omitted lunar day (*hīnadivasa*).

*Hīnadivasa* (हीनदिवस) Omitted lunar day.

*Hīnarātra* (हीनरात्र) Same as *Hīnadivasa.*

*Hutāśana* (हुताशन) Three.